REPORT 16

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05232/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

EFFECTS OF SUBSOILING ON CORN YIELDS AND SOIL CONDITIONS IN SOUTHWESTERN ONTARIO (1988 Growing Season)

FINAL REPORT

September, 1990

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STUDY TEAM

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ACKNOWLEDGEMENTS

Can-Ag Enterprises sincerely thanks the many co-operating farmers who very kindly offered their time, willingly provided information on their operations, permitted us to examine their fields, and weighed crop yields for each treatment. Their enthusiasm in attempting to overcome the soil degradation problem is most encouraging.

Special thanks are also extended to the agencies and individuals who contributed to this study, namely:

1. Southwestern Ontario Agricultural Research Corporation for heading up and administering the study.
2. The Scientific Authority, Dr. W. Findlay, Agriculture Canada, Research Station, Harrow, Ontario.
3. Ecological Services for Planning, Subprogram Manager, Guelph, Ontario.
4. The Soil Analysis Lab, University of Guelph, Ontario.

EXECUTIVE SUMMARY

Twelve farmers from Kent County in southwestern Ontario co-operated in this study to observe the effect of subsoiling on corn yields and soil conditions.

Problem

This study focused on the subsoiler performance in the soil layer below the plow depth (ie. about 15 to 30 cm below ground surface). This region within the soil profile is where compaction can occur. Soil compaction may include one or more of these conditions: degraded soil structure; reduced size, abundance and continuity of vertical cracks and pores; smearing; increased soil bulk density; layering; and, altered rooting pattern and depth. These conditions tend to reduce the soils' ability to produce abundant crops due to deterioration of root zone quality. Soil permeability is also reduced and this results in increased runoff and erosion.

A previous Can-Ag compaction study indicated that about 50 to 70 percent of the clay to clay loam soils in several southwestern Ontario counties are affected. Of this total, about 25% are severely compacted and 75% are moderately affected resulting in crop yield reduction, increased soil erosion, and increased phosphorus loadings to the Great Lakes.

Purpose

The purpose of the study was to evaluate the B.C. Sub-mulcher, a narrow shank subsoiler, pulled through corn rows at depths of 18 and 31 cm in June of 1988. Not only did we look at the soil and plant response to the subsoiling, but also to determine what other management practices may affect soil compaction and yields.

Measurements of Compaction

Several methods are used to measure soil compaction and five of the more popular ways were used in this study: visual observations of a combination of factors; bulk density determinations, hand and cone penetrometer measurements and detailed descriptions of soil peds and pores (tubular and planar).

Statistical Analysis

The degree of compaction was assessed using two kinds of statistical analyses; a Pearson Correlation matrix and an analysis of variance. The ANOVA established differences among subsoiling treatments with respect to yields and measured soil properties. The Pearson Correlation matrix was made to examine correlations among various parameters measured and described.

Results

The 1988 growing season lacked significant rainfall which contributed to below average yields. These abnormally dry conditions were excellent for the subsoiling operation but caused some yield loss in the subsoiling test strips.

Results indicate that shallow (18 cm) subsoiling was detrimental to yields: deeper subsoiling did not, on the average, have any effect. However, in the sites determined to be severely compacted, yields responded very favourably to deep subsoiling.

Subsoiling improved soil conditions, though these improvements were confined to a 20 cm width centered over the shank path.

An interesting management correlation showed an increase in yields with an increase in field operations, even though this has the potential to increase compaction. The dry season probably was the major factor for this observation. Since there was not any extensive periods of wet soil conditions during critical times for field operations, compaction associated with these operations did not occur. This points out the importance of proper timing of field operations in conjunction with soil conditions.

Recommendations

A few recommendations arising from this study concern the use of a post emergence subsoiler, especially in a dry year.

These include:

- pulling a packer behind the subsoiler to close the openings left by the subsoiler shanks to reduce moisture loss through evaporation;
- the use of a subsoiler after wheat harvest where the soil is dry and there is no resulting moisture stress on a crop; and
- further research on subsoiling timing and effects of implement design.

1. INTRODUCTION

Can-Ag Enterprises was contracted by Southwestern Ontario Agricultural Research Corporation (S.W.O.R.C.), which was funded by Supply and Services Canada on behalf of Agriculture Canada, to conduct this subsoiling study. This research was done as part of the Technology Evaluation and Development (TED) sub-program of the Soil and Water Environmental Enhancement Program (SWEEP).

Subsoil compaction, between about 15 and 30 cm below the ground surface, is considered to be a widespread problem in southwestern Ontario. In a previous study by Can-Ag Enterprises (1988), it was found that about 50 to 70 percent of the clayey soils in the Counties of Middlesex, Lambton, Essex, Kent and Elgin are affected. About a quarter of the affected soils were considered to be severely compacted and the remainder were rated moderately compacted. Important impacts of compaction were determined to be crop yield reductions, increased soil erosion and increased phosphorous runoff. Key factors found to be contributing to compaction included: size of tractor (bigger tractors matched greater compaction); number of passes (more passes matched greater compaction); and crop rotations (compaction increased in this order forages < grains < row crops < silage corn and tomatoes).

Amelioration of subsoil compaction through freeze - thaw and wetting - drying cycles is generally a very slow process which takes many years and is therefore not practical (based on studies in Minnesota and Ontario, by Thorud and Frissell 1976, Kay et al. 1985). This is particularly true of the fine textured soils. Gameda et al. (1987) have found that freezing and thawing cycles cannot relieve compaction in a fine textured soil in the short term in northern temperate countries. To date, the literature indicates that responses to subsoiling using heavy duty chisel plows and subsoilers have been mixed (Trouse et al. 1975, Colwick et al. 1981, Webster 1980). A major problem appears to be the timing of

subsoiling with respect to soil moisture conditions. Soils should be dry for effective subsoiling; however, in Ontario soils are often too wet in fall or spring when crops are not growing. Some studies, referred to above, also indicate that the beneficial effects of subsoiling are short-lived and subsoiling may have to be repeated every two or three years. On the other hand Duval et al. (1989) examined plots ten years after subsoiling and their results show that subsoiling of a compacted clay soil can be of long-term benefit to its soil structure.

The present study was initiated in May, 1988, to examine the effect of subsoiling between corn rows, in June. This approach permits subsoiling to be done under potentially drier soil conditions, and in 1988 soils at that time were dry. If crops were to respond favourably this would give a quick return on the farmer's extra input. Farmers clearly recognize the potential benefits and a group of twelve, in the Chatham area, were eager to undertake a two year study. Locations are shown in Figure 1. Specific objectives of the study were:

1. To determine corn yield response to subsoiling at a 18 cm and 31 cm depth using a BC sub-mulcher.
2. To examine soil conditions and characterize the degree of compaction and the response to subsoiling.
3. To evaluate the farming operation in general and determine what other management practices may affect soil compaction and yields.

Subsoiling was conducted in June 1988. Corn yields from test strips were measured at harvest, soils were examined and sampled after harvest but before fall cultivation, and farmers were interviewed after fall work to

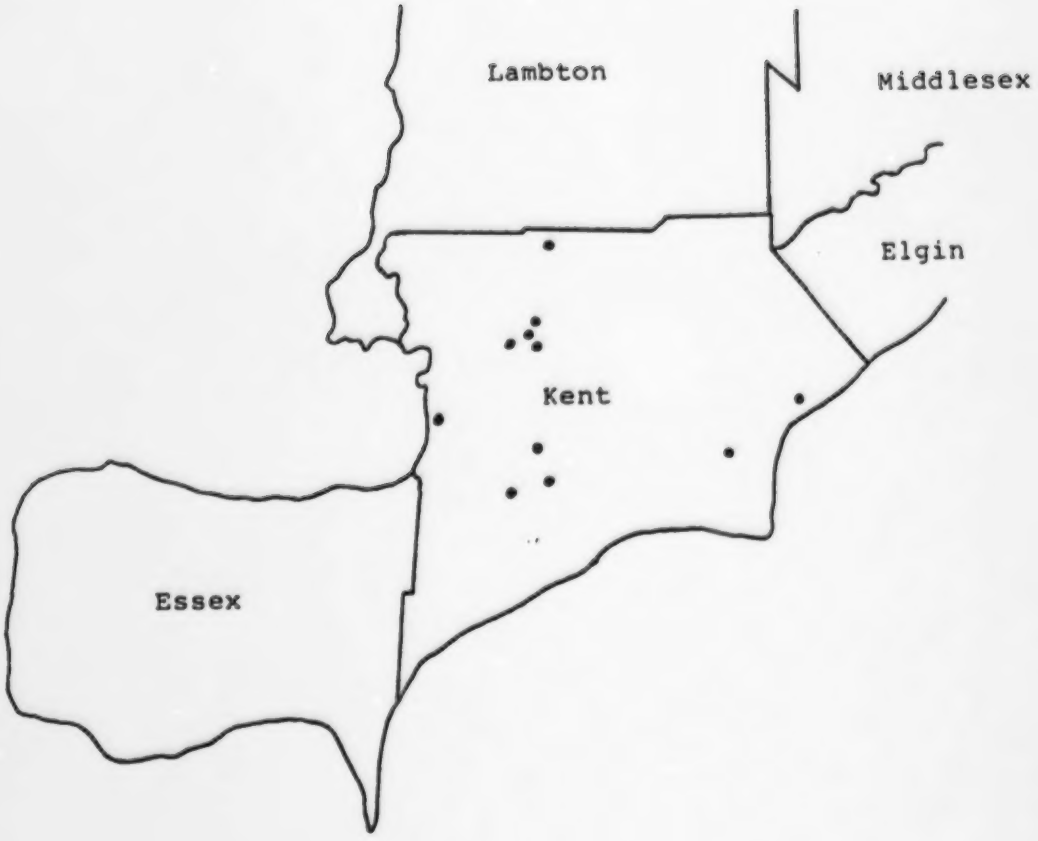


Figure 1. Location of Co-operators' Farms.

gather information on soil and crop management practices. This report describes the methods used, presents the results, discusses the implications, and makes recommendations for further research. Appendices provide definitions, summaries of field data collected, and tables of input data used in the statistical analyses.

2. METHODS

2.1 EXPERIMENTAL DESIGN

Test strips were established in farmers' fields in which three subsoiling treatments were applied:

Treatment 1 - no subsoiling
Treatment 2 - 18 cm (7 inch) subsoiling
Treatment 3 - 31 cm (12 inch) subsoiling

The test strips were field length and several corn rows wide allowing the harvester to make one or two rounds per strip. Headlands were omitted to avoid field edge effects. Yield measurements were made on one replicate per field. Soil investigations were conducted at two locations in each test strip, one near each end, and each location is considered a replicate in the statistical analysis. Therefore, there are at least twice as many soil replicates as yield replicates and caution is thus advised in interpreting the results. Diagrams showing the plot layout are given in Appendix A.

2.2 SOIL INVESTIGATIONS

In June, soil samples were taken at the time of subsoiling to determine soil moisture content. Next, detailed soil investigations within all treatments were made after harvest. A 50 cm deep soil pit was dug extending from one corn row to the next, thus allowing one to inspect the lateral and vertical effects of subsoiling. Soils were described in terms of horizons, depth, texture, structure,

consistence, earthworm counts and rooting. Abundance of pores and evidence of compaction were also noted in accordance with Tables 1 and 2, respectively. Composite samples from fields were taken from three depth intervals, roughly 0 to 15, 15 to 30, and 30 to 40 cm representing, respectively, the A horizon (topsoil or plow layer); the AB horizon (includes lower A and or upper B, and often compacted layer); and the B horizon (below the compacted or potentially compacted layer). Bulk densities of each layer were measured in duplicate at each sampling location. Density cores were regularly taken close to the corn rows to avoid direct effects of the subsoiler shank. A penetrometer (Dickey-John Manufacturer) was used to measure vertical penetration resistance at five equidistant points between corn rows, at 8 cm depth intervals to 48 cm. A pocket penetrometer was used to measure horizontal penetration resistance also at five equidistant points between corn rows, in the A, AB and B layers exposed on the side of the soil pit. Reported values for both penetrometers represent an average of five readings.

2.3 LABORATORY ANALYSIS

Composite soil samples representing each farmer's field were analyzed to determine soil pH, organic matter content, particle size distribution, and nutrient levels, specifically, phosphorus, potassium, magnesium and calcium. Soil bulk density cores were oven dried at 110°C for 24 hours to calculate density on a dry weight basis.

Table 1. Simple System for Describing Soil Macrostructure (from McKeague, et al., 1986).

I			Lacks an organized system of macrovoids and peds.
	1.*	IA	The material is massive and coherent.
		IB	The material is loose or single-grained.
II			Has a system of more-or-less vertical, tubular voids (channels) in apedal material.
		IIA	Channels 0.5 mm or larger in diameter occupy 0.1 to 0.5% of the volume of tubular voids can be estimated by using dot charts.
		IIB	Channels as specified above occupy more than 0.5% of the volume.
III			A system of more-or-less vertical cracks traverses the horizon; horizontal planar voids are weakly-developed or absent.
		IIIA	The cracks occupy less than 1% of the volume and vertical channels larger than 0.5 mm occupy less than 0.1% of the volume. (Volume of cracks can be estimated by measuring the total width of cracks in a1 m transect; for example, four cracks 2 mm wide in 1 m would indicate crack volume of 0.8%).
		IIIB	The cracks occupy more than 1% of the volume or cracks occur but occupy less than 1% of the volume and channels larger than 0.5 mm occupy more than 0.1% of the volume.
IV			A system of more-or-less horizontal planar voids partially or completely divides the material into platy units with less than 0.1% vertical tubular voids.
	2.	IVA	Planar voids are weakly expressed.
	2.	IVB	Planar voids are strongly expressed.
V			A system of planar voids in more-or-less horizontal and vertical directions partly to completely separates the material into blocky or prismatic peds with less than 0.1% vertical tubular voids.
	3.	VA	The planar voids are weakly developed and the partly-formed peds adhere.
	4.	VB	A well developed planar void system separates most of the material into peds.
VI			Vertical tubular voids occupy 0.1 to 0.5% of the volume and systems of vertical and horizontal planar voids occur.
	5.	VIA	Planar voids are weakly developed and the partly-formed platy, blocky or prismatic peds adhere.
	6.	VIB	Planar voids are well developed and most of the material occurs as peds.
VII			Vertical tubular voids occupy more than 0.5% of the volume and systems of vertical and horizontal planar voids occur.
	7.	VIIA	Planar voids are weakly developed and the partly-formed peds adhere.
	8.	VIIB	Planar voids are well developed and most of the material occurs as peds.

* Number denotes ranking used in correlation analysis.

Table 2. Soil Compaction Indicators: Subjective Rating (from Can-Ag Enterprises, 1988).

Compaction Indicators	Slight	Moderate	Severe
Structure	moderate to strong granular or subangular blocky	layered, deformed	massive, structureless, clods
Consistence	very friable or friable in A horizon, friable to firm in B horizon	firm in A & B horizon	very firm in A & B horizons
Soil pores	abundance of planar and tubular pores	few tubular pores, horizontal planar voids	lack of tubular & planar pores
Root Distribution	normal distribution of inped and exped roots	deformed rooting pattern	distinctive decrease in abundance in compact layer relative to layer above, root mat above compact layer
Earthworms	moderate to plentiful	few to moderate	none
Soil Water	uniform moisture distribution, little or no ponding after rains	restricted water percolation	surface ponding or ponding above compact layer after rains
Uniformity	above features found at all spot checks	above features variable	most above features observed at all spot checks

2.4 CROP YIELDS

Farmers harvested and weighed each treatment separately and calculated yields in bushels per acre. The 1988 corn yields discussed later in the report are the control (no subsoiling) yields. Average five year (1984-1988) corn and soybean yields reported by farmers are based on crop yields from the test field (and therefore do not represent five years of yield data for each crop).

2.5 FARMER INTERVIEWS

Co-operating farmers were interviewed to obtain information about their operations on the test fields. Questionnaires covered field operations: tractors used, horsepower rating, rear tire numbers and sizes, implements used and their widths, fertilizer application rates, and the farmer's assessment of his compaction problem.

2.6 STATISTICAL ANALYSIS

Basically two kinds of statistical analyses were undertaken. An analysis of variance was conducted to establish differences among subsoiling treatments with respect to yields and measured soil properties. Secondly, a Pearson correlation matrix was made to examine the correlations among the various parameters measured and described. A significant ($p = 0.05$) positive correlation indicates that as a parameter increases, the one it is being compared with is also expected to increase at least 95 percent of the time. A significant negative correlation indicates that as the level of one factor increases, the level of the other is expected to decrease. A cause and effect relationship is not implied although it may exist, and often there are important interactions among various factors that complicate the interpretations. These are discussed later in the report.

3. RESULTS

3.1 EFFECTS OF SUBSOILING TREATMENTS ON CORN YIELDS

Corn yields, reported in Table 3, are based on 1988 harvest results recorded by farmers as measured using a combine harvester and weigh wagon. Yields were generally below average due to severe drought during the spring and summer. Monthly rainfall for the growing season is shown in Table 4 and data indicate below average rainfall.

Effects of subsoiling treatments are statistically significant in that Treatment 2 (18 cm subsoiling) yielded lower than Treatment 1 (no subsoiling) or Treatment 3 (31 cm subsoiling). There were no significant differences between Treatments 1 and 3. Therefore, in 1988 shallow subsoiling was detrimental to yields: deeper subsoiling did not, on the average, have any effect. However, it is noteworthy that yields responded very favourably to deep subsoiling on soils considered to be severely compacted, as indicated for sites 3 and 8, Table 3. If more sites or replications with severely compacted soils had been included in the study it is likely that a statistically significant, positive response to deep subsoiling would have been measured.

While conditions were dry and considered to be ideal for subsoiling, it is thought that during the continuing drought the subsoiled strips dried out more than the control strips. This increased crop stress and caused yield reductions. Where there was severe compaction it appears that deep subsoiling improved the rooting depth or allowed limited rainfall to infiltrate deeper into the soil resulting in a net benefit to the crop.

Table 3. Corn Yields from Different Subsoiling Treatments (bu/acre), 1988.

Site	Subsoiling treatment 1 (0 cm)	2 (18 cm)	3 (31 cm)	Field average 1984-88	Compaction rating
1	146.4	128.9	127.5	160	moderate
2	58.0	41.6	61.4	103	slight
3	73.8	50.8	80.5	131	severe
4	141.5	145.3	138.5	136	slight
5	132.4	127.3	120.5	153	moderate
6	126.5	100.5	102.8	100	slight
7	92.8	93.4	94.5	129	slight
8	128.5	130.0	141.0	119	severe
9	--	--	--	--	severe
10	98.0	91.1	93.6	144	moderate
11	80.9	72.7	63.4	92	moderate
12	169.6	166.5	166.4	164	moderate
Mean	113.5a*	104.4b	108.2ab		

* Numbers followed by the same letter are not statistically different.

Amendment

Yield data for site 9 was obtained at a later date.

(0 cm): 124.3 (18 cm): 133.7 (31 cm): 135.4

The mean now becomes:

(0 cm): 114.4 (18 cm): 106.8 (31 cm): 110.5

The yields from this site correspond to previous findings for severe compacted soils -- refer to the third conclusion on page 21.

Table 4. Kent County Climatic Data.

Precipitation (mm) - 1988 data provided by the county OMAF office

Township	Apr	May	Jun	Jul	Aug	Sep	Oct
Camden	--	--	5.8	74.5	64.2	76.2	--
Camden	9.0	30.0	6.0	80.0	75.0	82.0	94.0
Chatham	18.0	13.0	3.0	--	--	--	--
Chatham	--	37.7	10.7	85.1	54.3	58.2	84.5
Dover	48.5	24.6	23.0	55.0	76.0	90.2	76.2
Dover	43.9	20.8	22.1	78.2	53.9	49.8	89.7
Harwich	54.1	33.3	14.7	125.7	59.7	61.0	83.8
Howard	41.0	44.0	14.5	71.0	76.0	64.5	94.5
Howard	--	37.3	.7	62.2	63.0	64.0	86.9
Orford	55.6	44.2	15.0	47.0	53.0	72.0	--
Orford	57.4	39.4	.7	55.6	53.3	88.9	115.1
Orford	--	40.4	12.0	48.1	56.4	65.6	82.9
Romney	35.0	43.0	14.0	57.5	39.0	--	75.0
Romney	41.0	48.0	21.5	69.0	35.0	48.0	73.0
Tilbury E.	43.5	12.0	3.5	93.0	69.0	26.5	--
Tilbury E.	--	12.0	0.0	89.5	--	--	--
Zone	16.0	40.0	19.0	64.0	47.0	--	--

Ridgetown College

1988 Climatic data

Rainfall (mm):	45.5	45.3	15.0	65.8	78.5	74.5	108.0
Heat units:	--	403.3	637.9	835.1	837.1	589.5	106.9

30 Year average

Rainfall (mm):	85.1	73.2	82.3	83.5	91.1	76.7	55.1
Heat units:	--	322.0	683.0	811.0	782.0	603.0	122.0

Note: The 1988 Kent County growing season precipitation data verifies the lack of rainfall that was observed throughout all counties of southwestern Ontario. The summary chart illustrates wide ranges in recorded levels resulting from bands of rainfall affecting different parts of the county contributing to the yield variability noted within Kent County.

On the basis of yield measurements in 1988 deep subsoiling (31 cm) is recommended, but only on soils that are severely compacted. However, because of the very few test sites with such soils and the abnormally dry conditions, further testing is required. Shallow subsoiling (18 cm) is not recommended.

3.2 EFFECTS OF SUBSOILING TREATMENTS ON SOIL PROPERTIES

Autumn measurements of soil properties on each treatment included cone penetrometer readings (vertical), pocket penetrometer readings (horizontal), bulk density, abundance of worms and size and abundance of pores. Average values and statistical significance are summarized in Table 5. Penetrometer readings indicate increasing resistance with increasing soil depth, as expected. Subsoiling to 18 cm reduced resistance to the 16 to 24 cm interval while subsoiling to 31 cm reduced resistance at all depths measured. Pocket penetrometer readings revealed a similar pattern. Note that the reading reported for each sampling point represents a mean of 5 readings, equally spaced from one corn row to the next. The "centre" reading was therefore usually within the subsoiler shank path, and considerably lower than the other readings on either side. Careful field inspection indicated that soil was loosened to the depth of subsoiling and about 8 to 10 cm on either side of the shank. In a one metre row width this represents about 20 percent of the inter-row area so the five readings are considered to give a representative reading.

Observations of root growth revealed that rooting was not responding to subsoiling in that there was no visible evidence that they grew towards the loosened area. Thus, while penetrometer readings indicated soil improvement following subsoiling this did not necessarily mean that it

Table 5. Significance of Soil Compaction Measurements in the Analysis of Variance.

Parameter	Subsoiling treatment		
	1 (0 cm)	2 (18 cm)	3 (31 cm)
Penetrometer reading PSI (mean of 5 readings per sample point, n = 36)			
DJ1 (0 - 8 cm)	92a*	67b	59b
DJ2 (8 - 16 cm)	174a	138b	136b
DJ3 (16 - 24 cm)	245a	216b	208b
DJ4 (24 - 32 cm)	298a	287ab	276b
DJ5 (32 - 40 cm)	346a	332ab	328b
DJ6 (40 - 48 cm)	371a	358ab	354b
Pocket penetrometer reading kg/cm^2 (mean of 5 readings per sample point, n = 36)			
PA (0 - 12 cm)	1.43a	1.30ab	1.29b
PAB (15 - 25 cm)	2.96a	2.66b	2.58b
PB (35 - 45 cm)	3.01a	2.88ab	2.73b
Bulk density g/cm^3 (x and y values represent duplicates for all, n = 36, except BDAx and BDAy, n = 33)**			
BDAx	1.38a	1.40a	1.37a
BDAy	1.38a	1.36a	1.39a
BDABx	1.49a	1.48a	1.48a
BDABy	1.48a	1.48a	1.46a
BDBx	1.59a	1.60a	1.57a
BDBy	1.58a	1.58a	1.57a
Worms (n = 36)			
WA	2.6a	2.6a	2.5a
WAB	2.4a	2.6a	2.6a
WB	2.6a	2.7a	2.8a
Pores (n = 36)			
POA	3.5a	3.8a	3.4a
POAB	3.8a	4.5b	4.6b
POB	4.7a	4.8ab	5.2b

* Values followed by the same letter are not significantly different, both vertically and horizontally.

** For 18 cm subsoiling, bulk density values at A, AB, and B soil layers significantly increased with greater depth ($p = 0.05$).

Note: See Appendix B for explanation of codes for each parameter.

would be helpful to the 1988 crops. It is possible that if, in 1989, crop rows were superimposed on the shank path, there could be residual benefits to subsoiling reflected in improved root penetration, better moisture movement and aeration. In several instances it was evident that subsoiling to 31 cm was not deep enough as the compacted layer extended a few centimetres deeper.

Bulk density measurements were routinely taken adjacent the corn rows to provide measurements unaffected by recent wheel traffic. In addition bulk densities were taken in a row centre from a randomly chosen rep. at each site. Data are reported in Tables 6 and A3 (see Appendix B) that indicate:

1. densities increased with depth, and;
2. subsoil density was reduced by subsoiling but only in the immediate vicinity of the shank path.

Earthworm abundance did not vary with soil treatment but soil porosity improved in response to subsoiling.

3.3 RELATIONSHIPS BETWEEN SOIL PROPERTIES AND MANAGEMENT FACTORS

Two Pearson correlation matrices were prepared to examine correlations among a wide range of soil properties and management factors. Correlation is a measure of the linear association of two variables where no cause and effect relationship is implied. A positive straight line association between two variables is such that as one increases in value, the other tends to increase as well. A negative correlation between two variables is such that as one variable tends to increase in value, the other decreases. No correlation between two variables (blank space on the matrix) is indicative of no linear association between them.

Table 6. Comparison of Soil Bulk Densities (g/cm^3) of Corn Rows verses Between Rows, in the 31 cm Subsoiling Treatments.

		Layer of soil					
		A		AB		B	
Site	Rep	Row	Centre	Row	Centre	Row	Centre
1	1	1.33	1.40	1.41	1.46	1.60	1.59
2	2	1.60	1.55	1.70	1.74	1.69	1.64
3	4	1.40	1.41	1.56	1.43	1.58	1.54
4	4	1.40	1.44	1.52	1.40	1.60	1.61
5	2	1.65	1.59	1.70	1.67	1.48	1.48
6	2	1.51	1.41	1.57	1.50	1.81	1.80
7	2	1.43	1.39	1.38	1.39	1.48	1.57
8	2	1.31	1.31	1.39	1.30	1.30	1.35
9	2	1.43	1.25	1.57	1.23	1.75	1.68
10	1	1.38	1.41	1.48	1.49	1.62	1.63
11	1	1.35	1.39	1.45	1.43	1.47	1.42
12	3	1.14	1.12	1.23	1.06	1.51	1.38
	Mean	1.41	1.39	1.50	1.43	1.57	1.56
	Standard deviation	0.13	0.12	0.14	0.18	0.14	0.13

i) Row vs centre is not significantly different for A.

ii) Row vs centre is significantly different for AB at 5% level.

iii) Row vs centre is not significantly different for B.

The first matrix included all sites of which four are on sandy soils and eight are on clayey soils. This showed that many factors were strongly correlated with texture and it was judged that compaction, moisture availability, and nutrient levels, for example, would markedly differ between sandy and clayey soils and this could mask the factors affecting compaction. Therefore, a second analyses was conducted excluding the four sandy sites. Results of the latter are summarized in Figure 2 and discussed below.

Cone penetrometer readings (DJ1 to DJ6) within two depth increments are generally positively correlated with each other. This is, higher readings at say 30 cm correspond to higher readings about 10 cm above and below. They are negatively correlated with silt percentage which means that as silt content increases, penetration resistance decreased.

Pocket penetrometer readings are closely linked to the cone penetrometer readings, especially in the B layer. They are negatively correlated with silt content and positively correlated with sand and clay content.

Bulk densities show many important and expected correlations. Densities of A, AB, and B layers are positively linked: as organic matter increases, the density decreases; as sand content increases and clay contents decrease, density increases.

Corn yields measured on plots in 1988 decreased as soil density, compaction severity, and sand content increased. On the other hand, 1988 corn yields increased as pore volumes, organic matter, clay content, and soil P and K levels increased. Average 1984 to 1988 corn yields on test fields as reported by farmers showed no relation to density, similar responses to texture and organic matter, a positive relationship to applied potassium, and positive correlations with number of passes, tractor tire coverage and cumulative loadings. The latter suggest that extra field operations tend

Figure 2. Pearson Correlation Matrix.
Note: See Appendix B for explanation of codes for each parameter.

to improve crop yields, even though the extra operations cause additional compaction. This is assuming that the number of operations made by each farmer in 1988 was more-or-less the same in each year since 1984.

Soybean yields were not measured in 1988; however, average yields since 1984 on these test fields, as reported by farmers, were included in the analysis. While caution is advised interpreting the results because soybeans were grown in different years on different farms there are several interesting patterns. Yields increased as: compaction rating increased; number of passes increased; clay content increased; soil magnesium level increased; and pH increased. Soybean yields decreased as: penetrometer resistance increased; and potassium fertilizer rates increased. These relationships suggest that soybeans respond positively to a well worked and firm seedbed.

In comparing corn and soybean yields it appears that extra field operations are beneficial; corn appears to be more sensitive to compaction and decreased porosity; and there is no relationship between yield, nitrogen applied and phosphorus applied. It is possible that crops are over-fertilized and factors other than nutrient supply are limiting yields? Considering that soil compaction, porosity, clay content and organic matter content all interact and govern soil moisture supply and root zone aeration it is judged that soil moisture management is a key factor in determining yields. Any management practices that lead to increasing soil moisture availability without restricting aeration, should contribute to higher yields.

Abundance of worms and soil pores in the AB and B layers are positively correlated. This is to be expected since many of the tubular pores are created by earthworms. Pores in the compacted layer (AB) decrease in abundance and size as bulk density, compaction and number of passes increase.

Compaction ratings of soils that were not subsoiled are used in the correlation analysis. As compaction increases bulk density in the A and AB layers increases, 5 year average soybean yields increase, 1988 corn yields decrease, and abundance of worms and pores decreases. Other significant relationships occur in connection with nutrient levels but these are difficult to explain.

Soil organic matter, sand, silt, and clay contents are all closely interrelated. In addition to linkages with yield and bulk density discussed previously, it is evident that organic matter increases are matched by increases in clay content, soil phosphorus and potassium increases, and decreases in sand content. As might be expected, it is evident that correlations of 1988 corn yield versus other parameters are very similar to soil organic matter versus other parameters. The combination of factors contributing to higher soil organic matter levels also contributed to higher 1988 corn yields.

Rates of fertilizer applied in 1988 and inherent nutrient levels in soils sampled in fall as reflected by routine soil analyses have been mentioned above in connection with several factors and the highlights are summarized as follows. Increased phosphorus and potassium rates match increased penetrometer resistance, which may be attributable to the increased traffic load, but this is not reflected in bulk density. Levels of nutrients in soils are positively correlated with organic matter and clay contents, as expected. The 1988 application rates of N, P or K are not correlated with levels of these nutrients in the soils, nor are they correlated with 1988 corn yields. Are soils being fertilized effectively, or did other factors such as those affecting moisture supply govern 1988 yields?

Soil reaction (pH) is positively or negatively correlated with several factors, for example: pH increases along with increased compaction, and increased nitrogen

applications, but decreased abundance of worms and pores. It may be that there is less leaching of bases in compacted soils, hence a higher soil pH level but calcium and magnesium levels are not correlated with pH.

Field operation considerations including tractor size, tire coverage, tractor weight, number of passes, and cumulative tractor weight (based on tractor size, number of passes, and implement width) were recorded in 1988 and included in the correlation analysis. Several expected as well as unexpected results occur. In the 1988 study of soil compaction on clayey soils, it was found that increasing tractor size (and weight) correlated positively with increasing compaction, and it was concluded that bigger and heavier tractors contributed to the compaction problem. It was also found that increasing the number of passes contributed to higher compaction. In the current study, comparing only clayey soils, soil bulk density and compaction rating decrease as tractor size increases, and as the number of passes decreases. However, in the correlation including all soils as well as clayey soils, there is a relationship between tractor sizes and sand content such that farmers on sandier soils have smaller tractors. This is logical in that power requirements for cultivation are greater and timeliness of operations is more critical on clayey soils. This may explain the apparent anomaly between soil density and tractor size: bigger tractors are used on clayey soils than on sandy soils but sandy soils have a higher bulk density. Clayey soils in turn tend to have more worms and pores than sandy soils, hence a positive relationship between tractor size and occurrence of pores. The assumption, that 1988 operations on each farm are typical of those in other years, must be applied with caution. For example, there are limitations to the data and interpretations of only one year of observation, with a small sample size (8 farms with clayey soils, 13 farms total), and the lack of replicated treatments on each farm. If some

farmers tend to work fields more often, and others less frequently, this could alter the interpretations relating to compaction, which is thought to be cumulative over a period of time. The sample size was considered to be too small to examine other factors such as effects of rotations, conservation versus conventional tillage, and role of manure. Nevertheless, many of the results provide important insights into the complexity of good soil husbandry.

4. CONCLUSIONS AND RECOMMENDATIONS

In June 1988, a study on the effects of subsoiling in thirteen corn fields indicated several important findings. Caution is advised in extrapolating the results, for 1988 was a very dry year. The findings may not necessarily reflect those under average and longer term conditions.

1. Shallow subsoiling (18 cm) was harmful to crop growth and was too shallow to penetrate the compaction layer where present; therefore, shallow subsoiling is not recommended based on the one year study.
2. Deep subsoiling (31 cm) resulted in no average yield difference when compared to control plots (no subsoiling), considering all fields. It is noteworthy that deep subsoiling was effective in overcoming the impact of shallow subsoiling.
3. Sample size was too small (two fields) to detect statistical significance, but there was a good yield response (10 percent increase) to deep subsoiling on the two severely compacted sites. On this basis, deep subsoiling is only recommended on severely compacted soils.

4. Soil conditions improved especially in the deeper subsoiling treatments as measured by penetrometer, soil bulk density and occurrence of soil pores, but this improvement was confined to the shank path, about a 20 cm width to depth of subsoiling at roughly 1 m intervals. Hence about 20 percent of the land area would be improved in one subsoiling operation.
5. Correlation analysis indicated many expected relationships among soil chemical and physical properties, and management practices. Practices which tend to increase soil organic matter levels, improve soil moisture retention, and allow good aeration are highly recommended. A lack of yield response to increasing fertilizer applications suggests that either these are incorrect or that 1988 was too dry and other factors, likely moisture availability, governed yields. Increasing the number of field operations tended to improve yields even though they may also have tended to increase compaction. This implies that timing of operations with respect to soil conditions could be critical. Do not work soils when they are wet as this contributes to compaction but operations during normal conditions help to increase corn yields.
6. Further testing is recommended and is to be continued to examine the following:
    1. effects of deep subsoiling in corn, in June, to determine responses under different climatic conditions;
    2. effects of pulling a packer behind the subsoiler to close the openings left by

the subsoiler shanks to reduce moisture loss through evaporation (to be done in June, in corn);

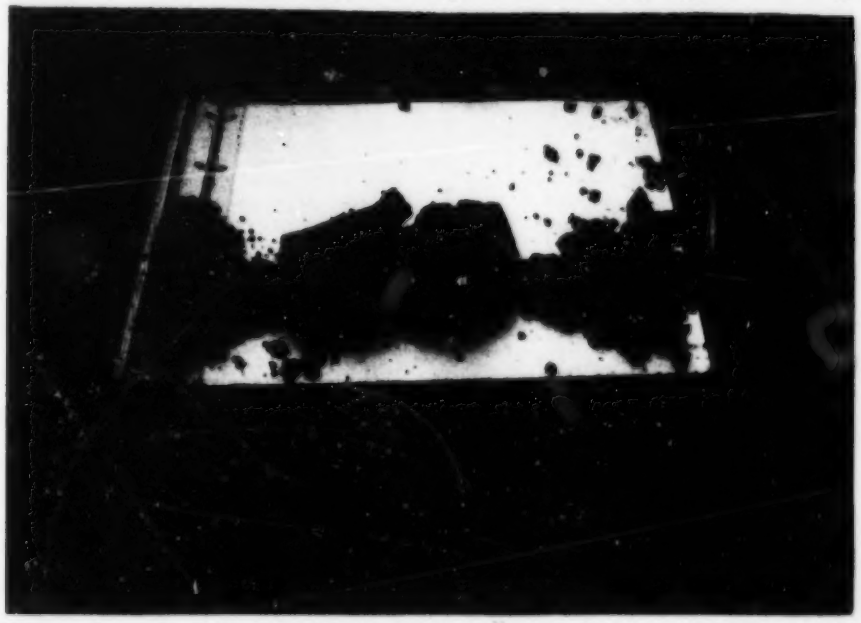
3. effects of subsoiling in fall, after soybean or winter wheat harvest, on next year's wheat crop; and
4. effectiveness of different subsoiling implements.

In all cases, replicated test plots are recommended, soil management practices should be monitored and soil properties should be described or measured as in 1988.

5. PHOTOGRAPHS

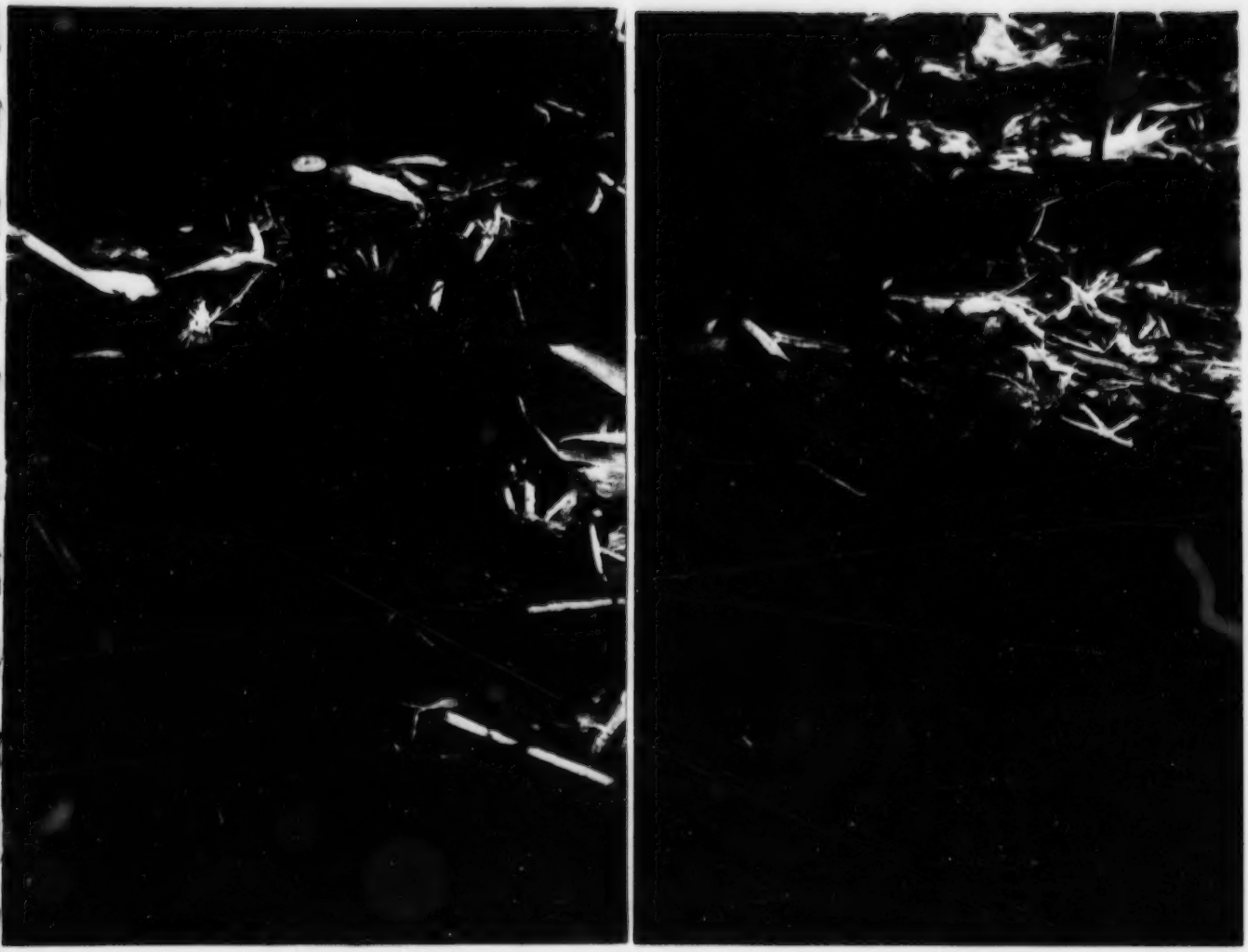
The following photographs provide a sample of soil and agronomic characteristics encountered.

Picture 1. Pit showing an angular blocky type soil profile.



Picture 2. A non-compact AB horizon (1*) compared with a compact AB(2). A compact B(3) compared with a non-compact B(4).

* observing the four samples from left (1) to right.



Pictures 3 and 4. Note the vertical corn root growth in the non-compact soil (left) verses the more lateral growth in the compact soil (right).

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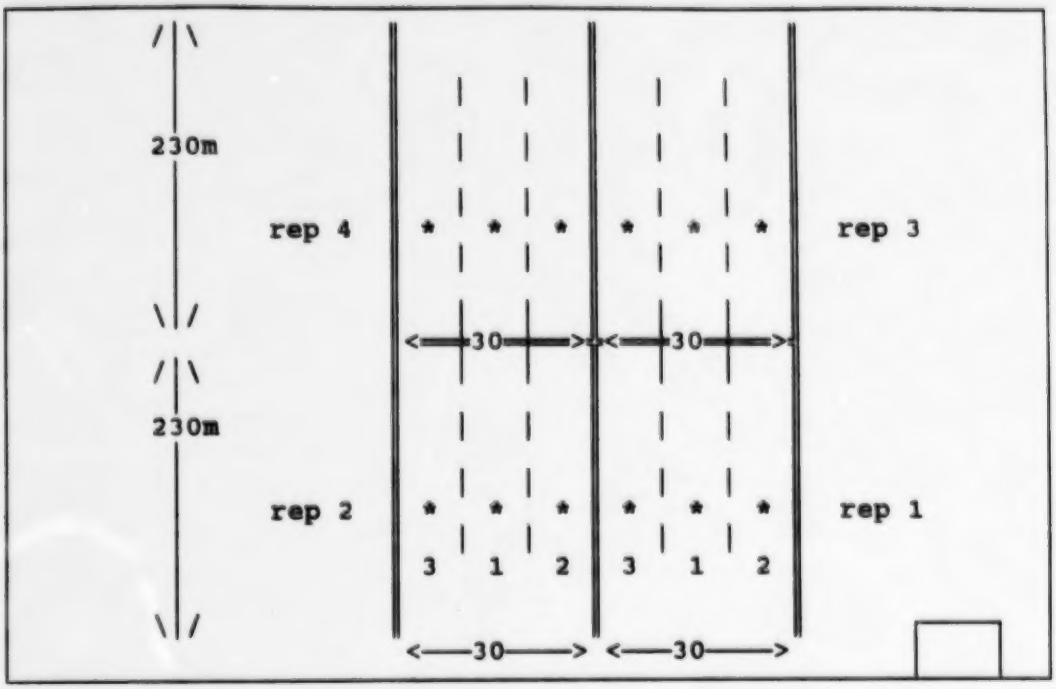
7. APPENDICES

7.1 APPENDIX A

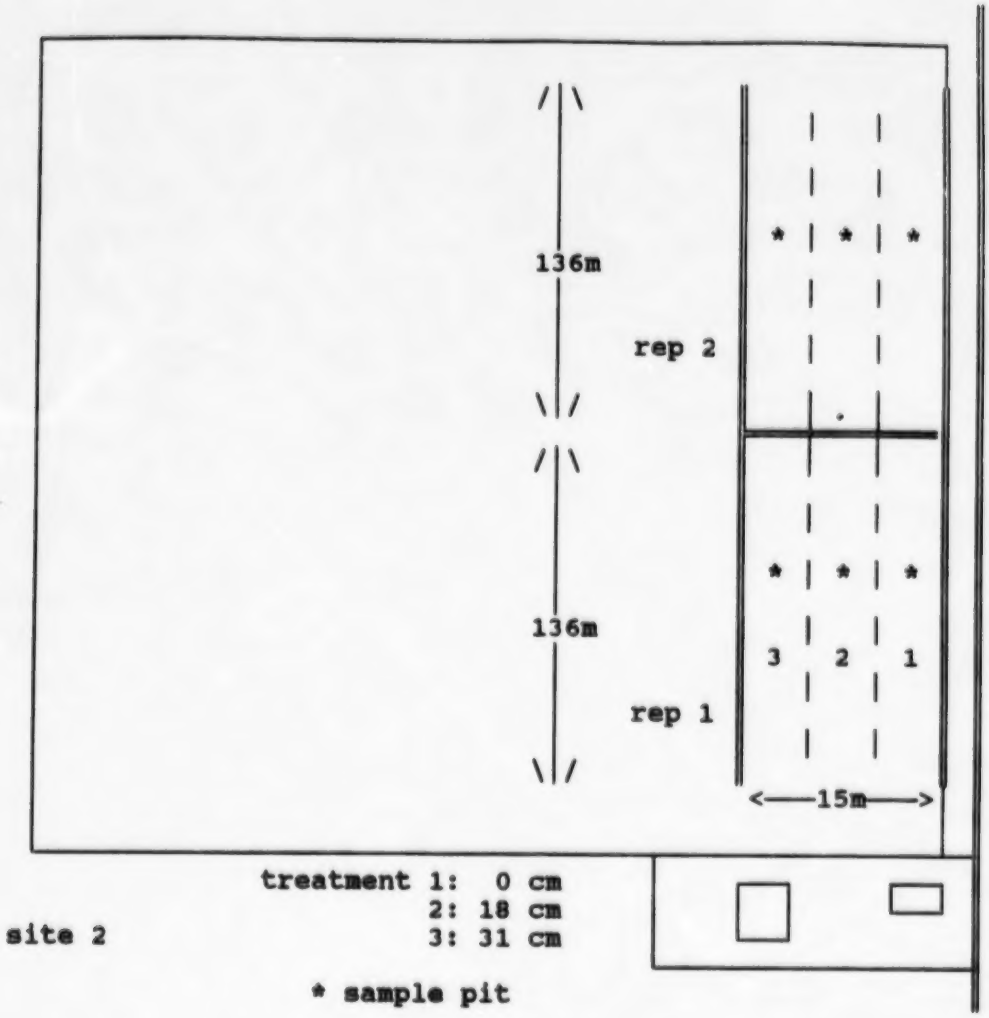
PLOT LAYOUT

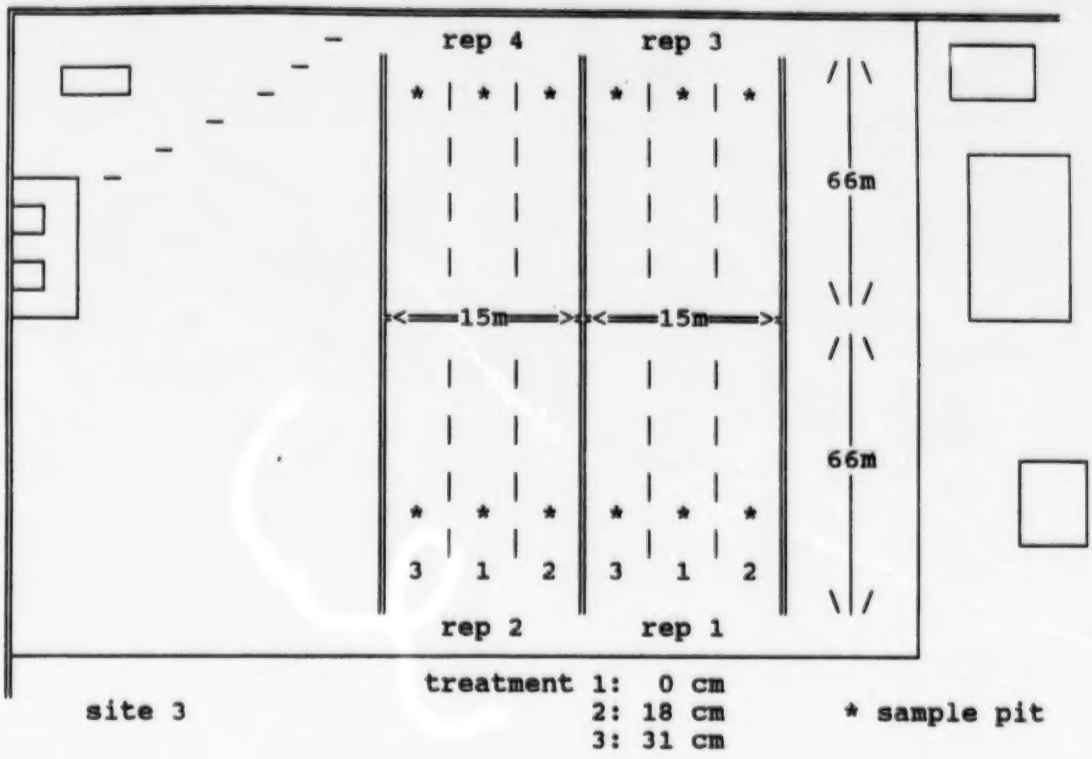


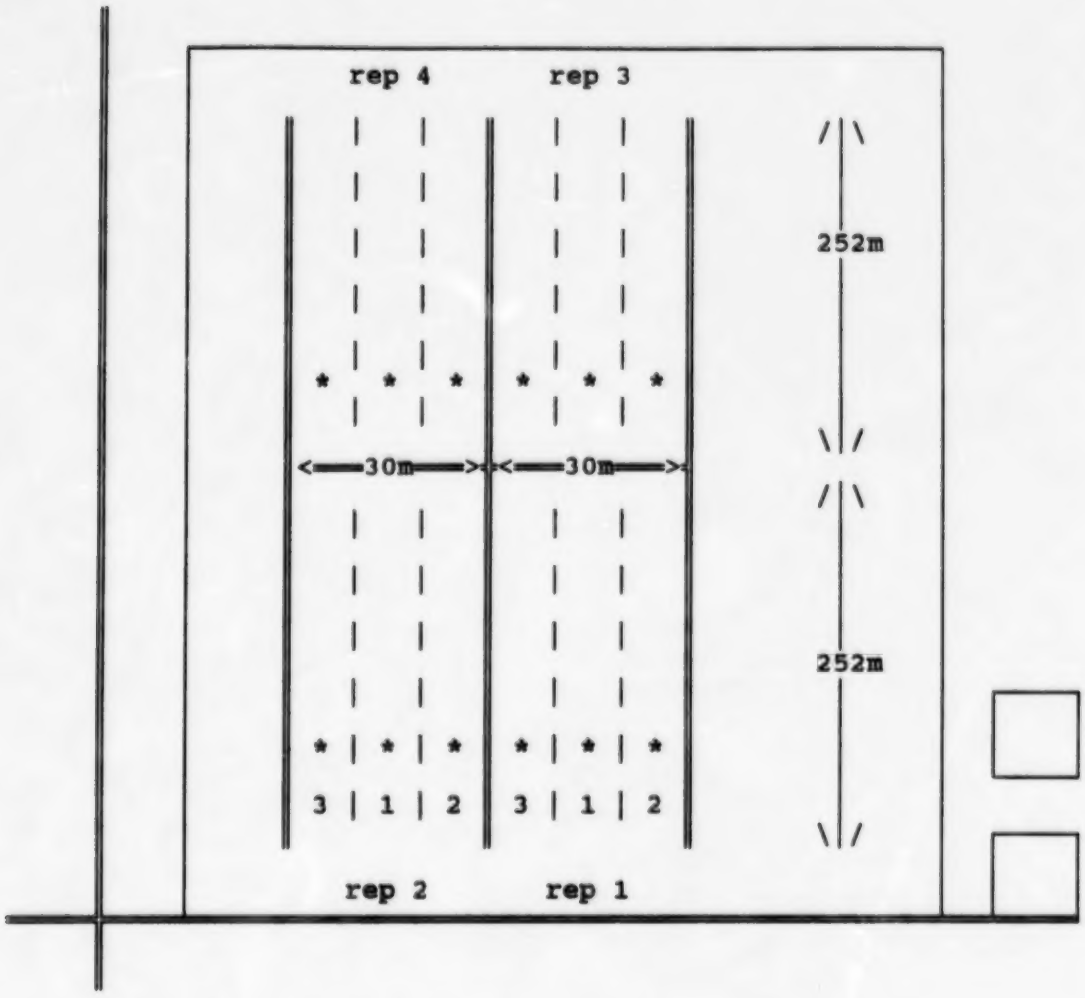
site 1

treatment 1: 0 cm
2: 18 cm
3: 31 cm

* sample pit

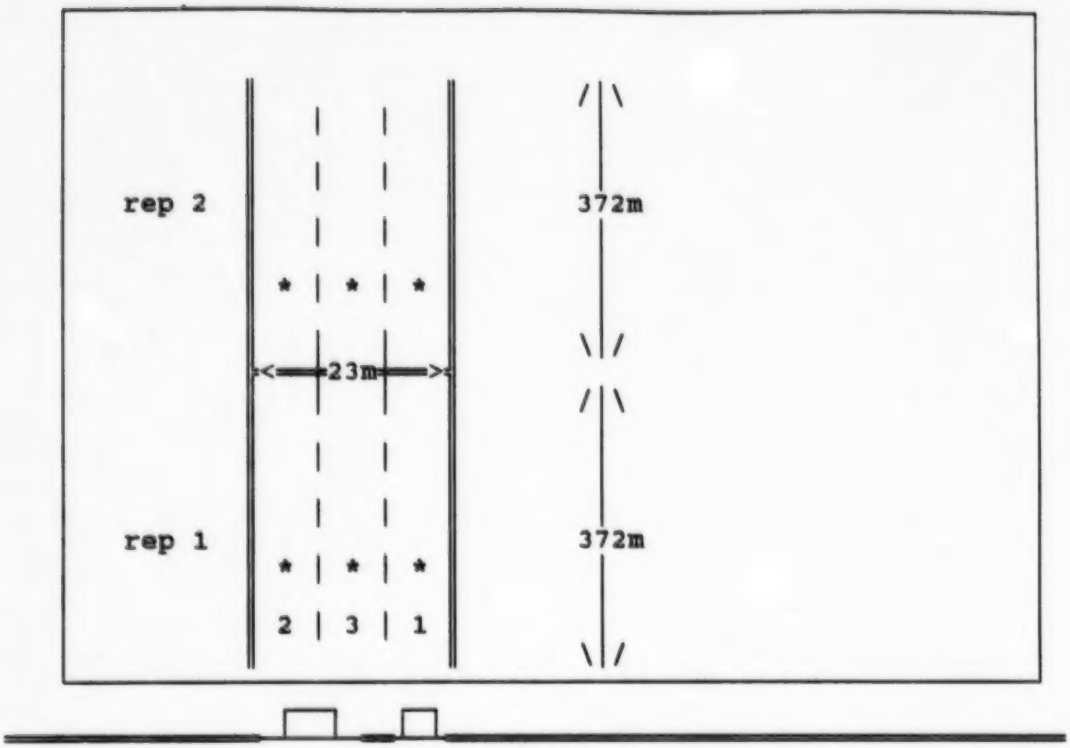

136m
rep 2
136m
3
2
1
rep 1
<——15m——>
treatment 1: 0 cm
2: 18 cm
3: 31 cm
site 2
* sample pit


rep 4
rep 3
66m
15m
15m
66m
3 1 2
3 1 2
rep 2
rep 1
treatment 1: 0 cm
2: 18 cm
3: 31 cm
site 3
* sample pit



site 4 treatment 1: 0 cm
2: 18 cm
3: 31 cm

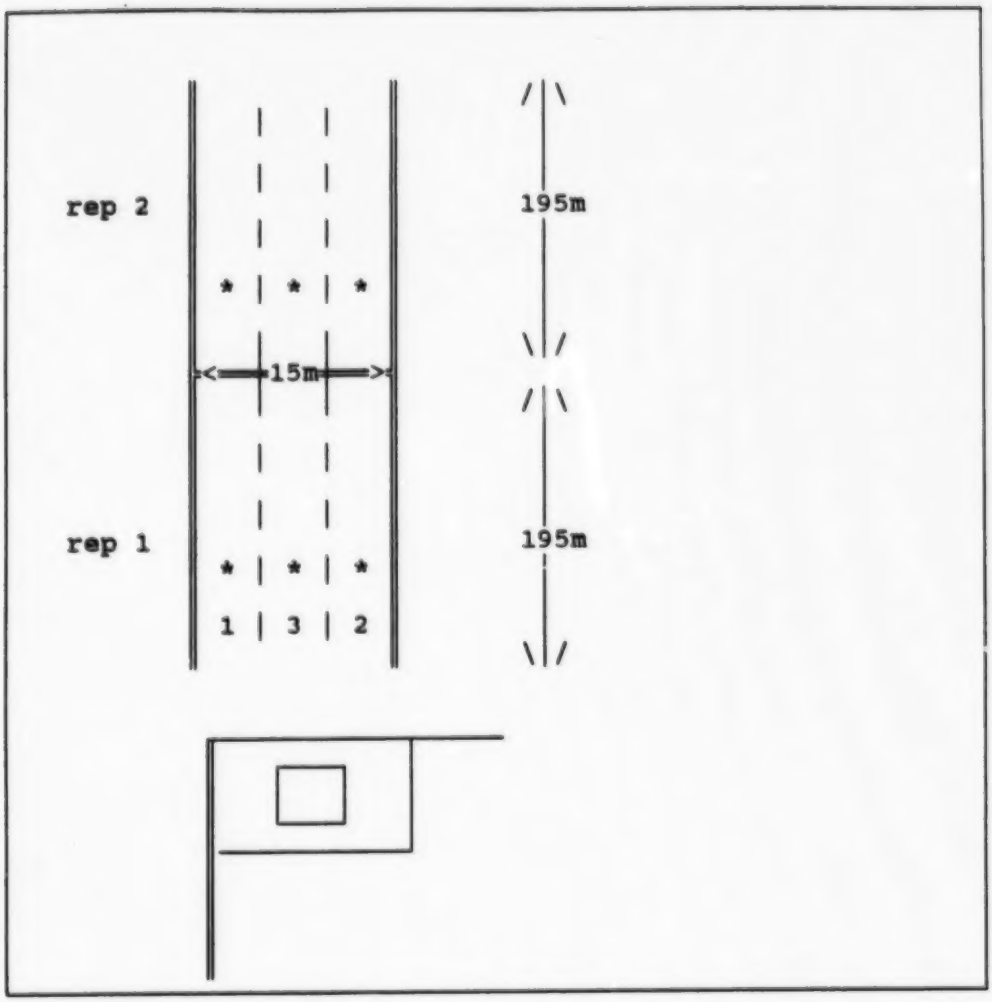
* sample pit



site 5

treatment 1: 0 cm
2: 18 cm
3: 31 cm

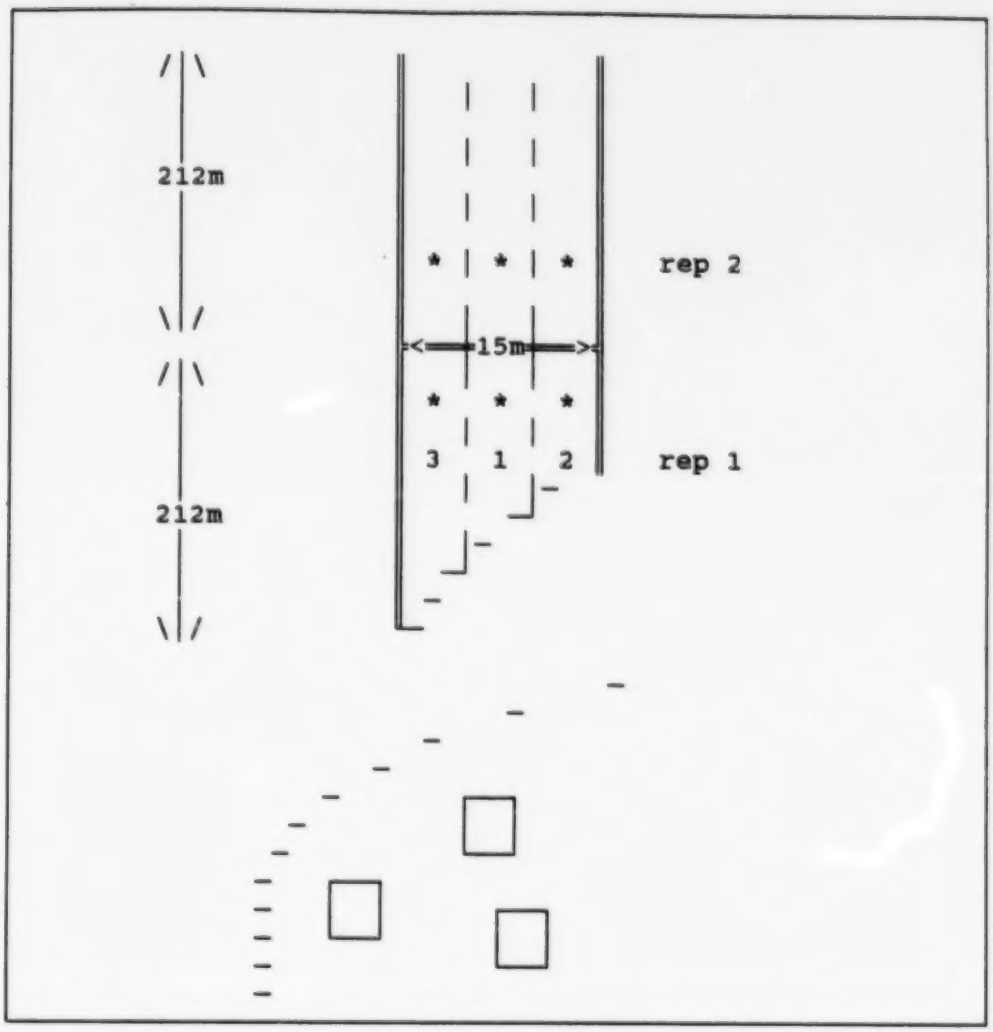
* sample pit



Site 6

treatment 1: 0 cm
treatment 2: 18 cm
treatment 3: 31 cm

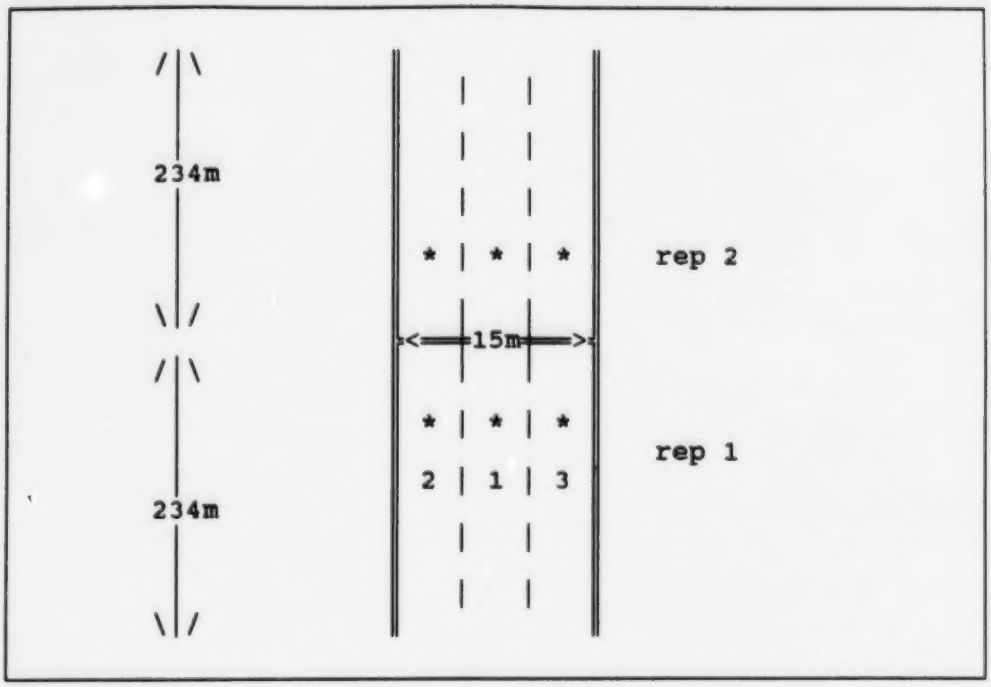
* sample pit



Site 7

treatment 1: 0 cm
treatment 2: 18 cm
treatment 3: 31 cm

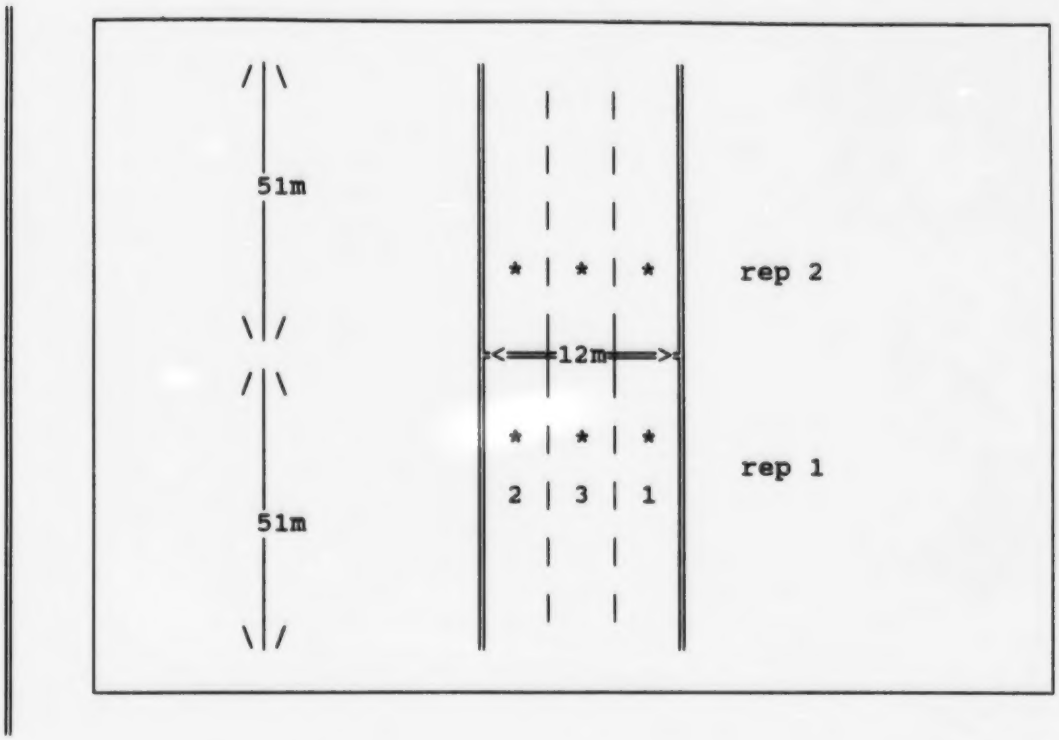
* sample pit



Site 8

treatment 1: 0 cm
treatment 2: 18 cm
treatment 3: 31 cm

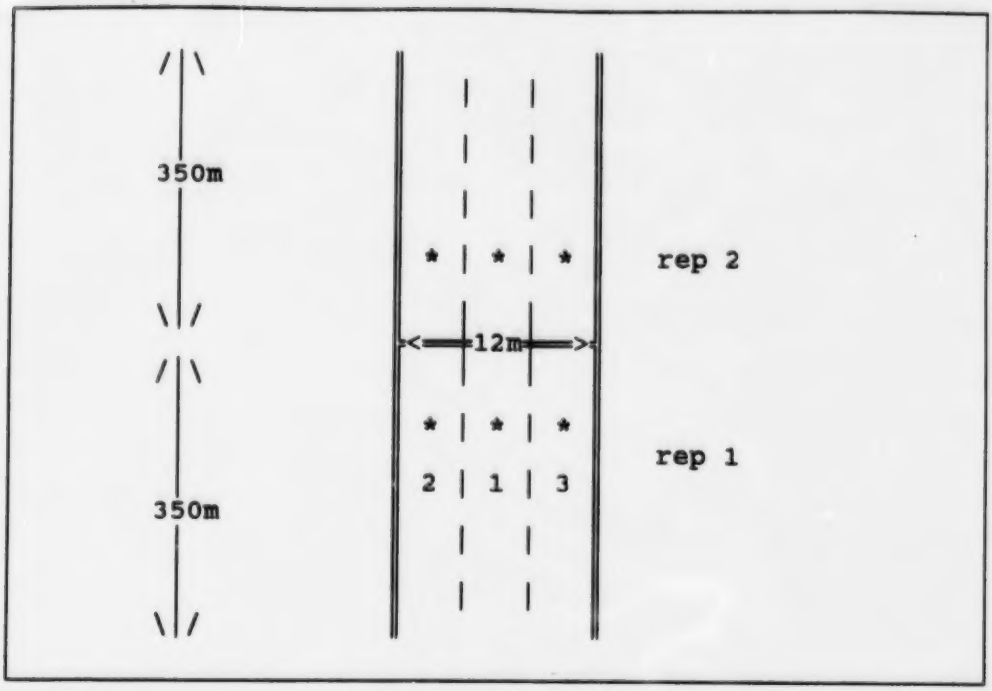
* sample pit



Site 9

treatment 1: 0 cm
treatment 2: 18 cm
treatment 3: 31 cm

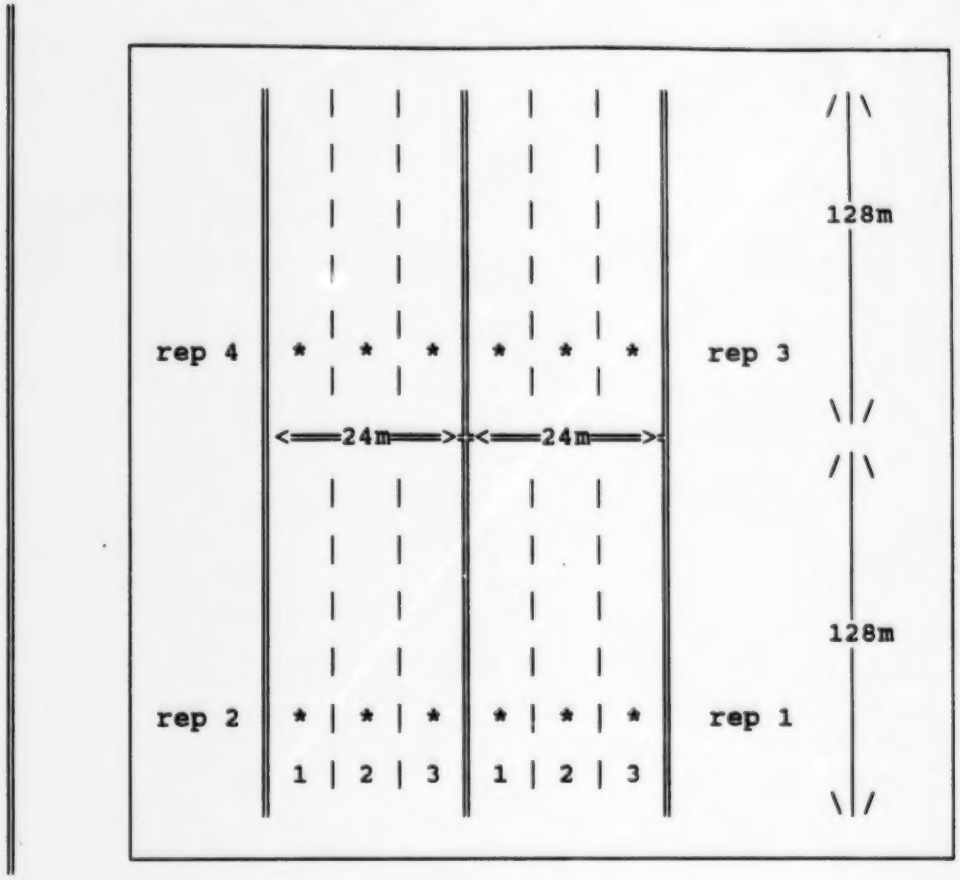
* sample pit



Site 10

treatment 1: 0 cm
treatment 2: 18 cm
treatment 3: 31 cm

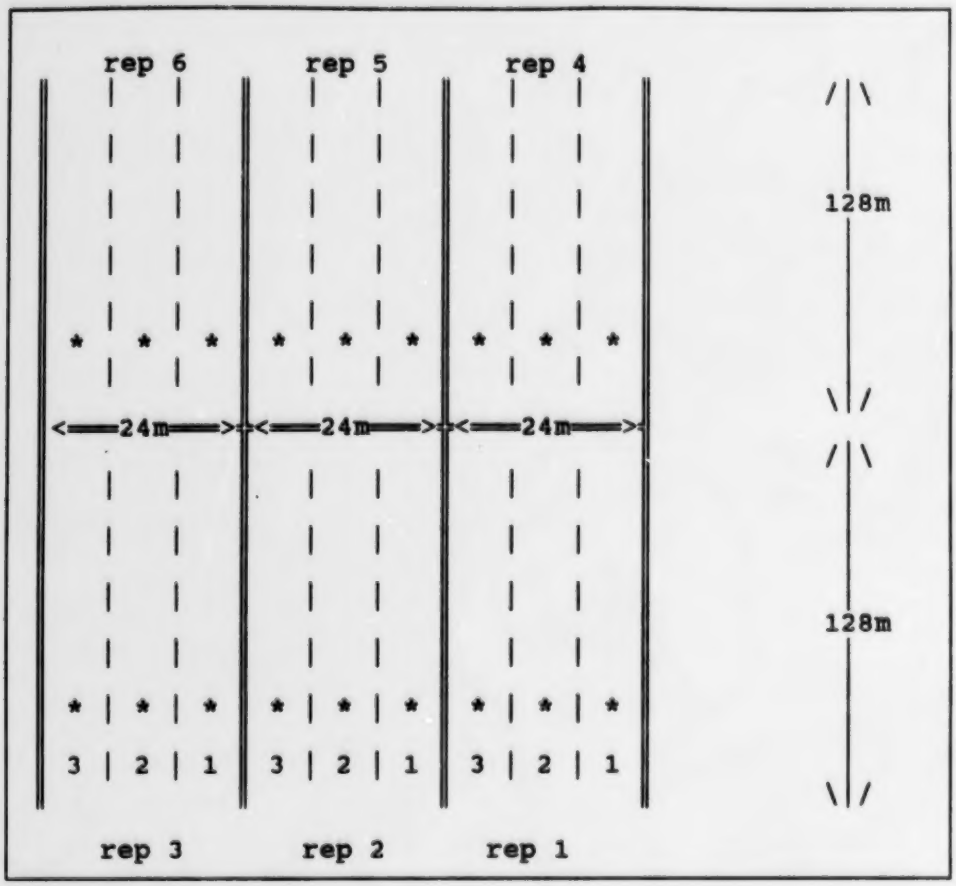
* sample pit



site 11

treatment 1: 0 cm
2: 18 cm
3: 31 cm

* sample pit



site 12

treatment 1: 0 cm
2: 18 cm
3: 31 cm

* sample pit

7.2 APPENDIX B

Variables used in Pearson Correlation Analysis - Codes and Explanations.

DJ 1 to 6 Dickey-john penetrometer reading (maximum).

DJ1	0 - 8 cm
DJ2	8 - 16 cm
DJ3	16 - 24 cm
DJ4	24 - 32 cm
DJ5	32 - 40 cm
DJ6	40 - 48 cm

P Pocket penetrometer reading (maximum).

P A	in A horizon (approx. 0 - 12 cm)
P AB	in AB horizon (approx. 12 - 25 cm)
P B	in B horizon (approx. 25 - 35 cm)

BD Bulk density, g/cm^3 dry weight basis.

BD Ax, Ay	represent duplicates in A horizon
BD ABx, ABy	represent duplicates in AB horizon
BD Bx, By	represent duplicates in B horizon

Yield Critical yield obtained using a weigh wagon at the actual treatment site.

W Earthworm abundance based on a field estimate of earthworm numbers in a 25 x 25 cm square 10 cm thick, in the A, AB, or B layer.

1 = none to few	2 = few (< 5)
3 = moderate (5 - 10)	4 = many (> 10)

PO Pores in each layer A, AB and B, in accordance with the classes of McKeague et al (1986) simple system ranked as follows to reflect increasing pore volume.

1 = IA	2 = IVA or IVB
3 = VA	4 = VB
5 = VIA	6 = VIB
7 = VIIA	8 = VIIB

CR Compaction rating, a subjective numerical rating based on appearance and consistence of the AB layer in relation to the B layer and to undisturbed (fence-row) soils.

Y5 Corn Farmer's reported average corn yields in bu/acre, 1984 to 1988, on the test field.

Y5 Soy Farmer's reported average soybean yields in bu/acre, 1984 to 1988, on the test field.

FACA	Farmer's compaction assessment of his land. 1 = slight 2 = moderate 3 = severe
TT Cov.	Tractor Tire coverage per year calculated on a percentage basis considering rear tire width, number of rear tires, number of operations, and width of implement. No correction is made for repeat tracking. For example, total rear tire width in feet x number of passes per 100 feet width x number of operations = total tire coverage per year in %. [6 feet x 100/15 (for a 15 foot implement) x 6 operations = 238% coverage]
Pass	Number of passes, or field operations, in 1988. Subsoiling was included as an operation but harvesting was omitted, and this applies to all farms.
OM	Organic matter content in percent, in the A, AB and B layers.
Sand	Sand content in percent, in the A, AB and B layers.
Silt	Silt content in percent, in the A, AB and B layers.
Clay	Clay content in percent, in the A, AB and B layers.
N add	Total amount of fertilizer nitrogen applied in 1988, in lbs/acre.
P add	Total amount of fertilizer phosphorus applied in 1988, in lbs/acre.
K add	Total amount of fertilizer potassium applied in 1988, in lbs/acre.
P fert (ppm)	Phosphorus fertility level based on soil tests, sampled in October 1988, in the A layer.
K fert (ppm)	Potassium fertility level based on soil tests, sampled in October 1988, in the A layer.
Mg fert (ppm)	Magnesium fertility level based on soil tests, sampled in October 1988, in the A layer.
Ca fert (ppm)	Calcium fertility level based on soil tests, sampled in October 1988, in the A layer.

pH	Soil reaction, in the A layer.
Cum Wt/Ft	Estimated total loading by tractors per 100 foot width of field, (implements excluded) considering tractor total weight, number of passes per 100 foot width and number of operations.
T1HP	Tractor 1 horsepower. The horsepower rating of the farmer's largest tractor.
T2HP	Tractor 2 horsepower. The horsepower rating of the farmer's second largest tractor.
T3HP	Tractor 3 horsepower. The horsepower rating of the farmer's third largest tractor.

Table A1. Measurements of Soil Parameters and Corn Yields for Each Treatment on Each Farm. (Input data for analysis of variance).

SITE NO.	TRT	REP	DICKEY-JOHN 1	2	3	4	5	6	POCKET A	AB	B	BULK DENSITY Ax	Ay	ABx	ABy	Bx	By	YIELD	FERTILITY A	AB	B	A	AB	B	A	AB	B	A	AB	B	WORMS A	AB	B	PORES A	AB	B	CR
																			---P---			-----K-----			----Mg----			-----Ca-----			-----pH----						
1	1	1	25	90	176	275	370	385	2.0	3.7	3.5	1.35	1.33	1.59	1.50	1.55	1.63	146.4	32	38	6	240	251	152	397	372	367	4832	5916	6078	6.7	7.1	7.6	3	2	3	6	4	6	4
1	1	2	40	140	225	340	370	395	1.7	3.2	3.0	1.26	1.34	1.55	1.50	1.62	1.60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	8	4	6	.
1	1	3	80	120	180	270	300	315	2.3	3.1	2.8	1.40	1.56	1.59	1.55	1.57	1.59	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	2	8	4	4	.
1	1	4	95	145	255	293	290	330	1.6	3.1	2.7	1.43	1.43	1.55	1.54	1.63	1.63	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	7	4	3	.
1	2	1	30	160	200	255	330	355	3.5	3.9	4.4	1.40	1.26	1.34	1.29	1.58	1.47	128.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	8	4	6	.
1	2	2	0	30	135	300	380	380	1.0	3.4	3.8	1.34	1.45	1.54	1.47	1.61	1.68	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	7	3	6	.
1	2	3	0	0	10	105	190	260	1.3	2.8	2.6	1.46	1.47	1.43	1.64	1.59	1.65	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	7	3	6	.
1	2	4	100	175	200	340	370	385	1.4	2.7	2.2	1.50	1.49	1.54	1.65	1.54	1.57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	8	4	6	.
1	3	1	0	10	70	290	320	385	2.3	3.6	3.6	1.39	1.44	1.46	1.42	1.65	1.62	127.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	3	6	6	.
1	3	2	0	30	90	225	365	390	1.6	2.5	3.2	1.24	1.27	1.53	1.51	1.61	1.61	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	8	3	6	.
1	3	3	0	30	70	200	280	300	1.1	2.6	2.6	1.51	1.41	1.49	1.49	1.64	1.52	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	7	4	4	.
1	3	4	40	100	185	235	290	315	1.3	2.6	2.5	1.42	1.43	1.56	1.51	1.54	1.61	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	8	4	5	.
2	1	1	20	195	390	400	400	400	0.8	4.2	4.4	1.71	1.50	1.74	1.70	1.65	1.53	58.0	84	36	13	131	96	80	137	122	112	2068	1827	1569	7.3	7.5	7.5	2	3	2	1	5	2	2
2	1	2	0	110	225	320	335	370	0.9	1.9	3.3	1.59	1.58	1.64	1.65	1.65	1.69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	.	4	2	.
2	2	1	20	110	300	275	305	290	1.4	3.3	2.7	1.60	1.49	1.78	1.80	1.79	1.79	41.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	2	1	1	3	.
2	2	2	10	80	225	350	360	390	1.1	3.0	3.2	1.49	1.45	1.71	1.64	1.62	1.69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	5	4	6	.
2	3	1	80	260	295	310	320	305	1.8	2.9	2.5	1.27	1.61	1.70	1.71	1.69	1.72	61.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	1	3	5	.
2	3	2	0	190	290	330	400	365	1.3	3.6	2.9	1.58	1.61	1.74	1.66	1.64	1.73	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	1	5	5	.
3	1	1	90	180	185	325	380	400	2.5	3.2	2.7	1.46	1.56	1.78	1.71	1.63	1.63	73.8	25	27	4	139	136	94	350	363	502	3771	4426	2726	7.2	7.4	7.2	3	2	3	6	3	5	6
3	1	2	130	190	240	300	320	350	1.5	3.5	3.5	1.63	1.52	1.72	1.72	1.65	1.54	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	1	3	.
3	1	3	150	230	300	365	385	400	1.6	3.6	3.8	1.51	1.54	1.58	1.53	1.65	1.59	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	2	1	1	4	.
3	1	4	140	221	280	310	345	380	1.6	3.2	3.5	1.32	1.42	1.49	1.59	1.65	1.64	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	3	3	6	.
3	2	1	30	130	165	360	400	400	1.9	2.4	3.3	1.67	1.27	1.68	1.76	1.73	1.60	50.8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	3	6	5	.
3	2	2	40	145	190	340	400	400	1.8	2.3	2.4	1.57	1.65	1.62	1.58	1.67	1.68	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	4	2	.
3	2	3	105	180	200	345	390	400	1.5	3.0	3.4	1.49	1.43	1.66	1.57	1.71	1.67	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	1	4	6	.
3	2	4	140	175	290	300	355	370	1.4	3.7	3.7	1.52	1.48	1.62	1.57	1.61	1.62	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	1	3	3	3	.
3	3	1	0	135	180	320	370	400	1.7	1.9	1.8	1.64	1.67	1.57	1.64	1.65	1.57	80.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	1	4	5	.
3	3	2	35	100	180	270	280	285	2.1	2.6	2.5	1.55	1.65	1.62	1.69	1.66	1.57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	4	3	.
3	3	3	100	205	280	305	340	355	1.5	2.6	2.8	1.37	1.57	1.59	1.47	1.61	1.60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	3	4	4	.
3	3	4	100	165	305	360	370	380	1.8	2.7	3.5	1.42	1.37	1.49	1.62	1.53	1.63	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	3	4	4	.
4	1	1	90	180	230	320	365	390	1.9	2.6	3.5	1.28	1.27	1.39	1.30	1.55	1.57	141.5	62	69	12	233	229	157	229	346	357	2757	2560	1888	6.1	6.1	6.8	3	3	3	8	6	5	2
4	1	2	140	190	270	305	335	295	1.5	2.6	3.0	1.32	1.21	1.45	1.27	1.50	1.53	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	7	6	6	.
4	1	3	95	195	255	315	365	375	1.5	3.1	3.2	1.46	1.42	1.49	1.46	1.62	1.51	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	3	3	7	6	6	.
4	1	4	80	160	235	260	300	355	1.5	2.6	3.0	1.38	1.23	1.47	1.47	1.54	1.57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	3	7	8	6	.
4	2	1	0	40	110	250	290	325	1.2	2.5	2.9	1.28	1.19	1.29	1.35	1.40	1.48	145.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	3	7	8	5	.
4	2	2	60	160	240	295	315	365	1.6	2.7	2.8	1.28	1.23	1.34	1.35	1.43	1.44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	3	8	8	6	.
4	2	3	80	150	205	270	315	350	1.2	2.2	2.8	1.32	1.39	1.45	1.35	1.50	1.55	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	7	6	6	.
4	2	4	80	150	225	305	330	360	1.4	2.3	3.4	1.39	1.39	1.56	1.44	1.62	1.62	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	8	6	6	.
4	3	1	110	165	220	290	360	390	1.4	1.5	3.1	1.29	1.28	1.30	1.26	1.51	1.50	138.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	3	3	7	5	6	.
4	3	2	10	105	205	270	305	355	1.1	2.6	3.1	1.32	1.21	1.31	1.34	1.45	1.49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	3	8	8	6	.

Table A1. Measurements of Soil Parameters and Corn Yields for Each Treatment on Each Farm. (Input data for analysis of variance) (Continued).

SITE NO.	TRT	REP	DICKEY-JOHN 1	2	3	4	5	6	POCKET A	AB	B	BULK DENSITY Ax	Ay	ABx	ABy	Bx	By	YIELD	FERTILITY A	AB	B	A	AB	B	A	AB	B	A	AB	B	WORMS A	AB	B	PORES A	AB	B	CR
																			---P---			----K----			---Mg---			----Ca----			---pH---									
4	3	3	95	160	210	285	325	370	1.4	2.8	2.9	1.35	1.53	1.53	1.40	1.59	1.60	.																3	4	3	7	8	6	.
4	3	4	105	150	220	290	310	355	1.2	2.7	2.8	1.33	1.46	1.56	1.48	1.61	1.58	.																3	3	3	7	6	6	.
5	1	1	90	160	215	265	330	400	1.3	2.5	3.3	1.46	1.46	1.62	1.55	1.73	1.73	132.4	52	57	15	382	189	235	105	126	149	2597	3562	3652	5.4	5.5	6.2	3	3	3	1	5	5	4
5	1	2	105	185	280	205	370	400	1.2	2.6	3.4	1.47	1.45	1.55	1.63	1.66	1.63	.																3	3	3	1	1	6	.
5	2	1	40	125	245	200	240	330	0.8	2.6	2.5	1.52	1.48	1.62	1.59	1.61	1.71	127.3	.															3	3	3	5	5	5	.
5	2	2	80	170	250	310	260	275	1.2	3.0	3.2	1.50	1.55	1.59	1.62	1.61	1.59	.																3	3	3	5	5	5	.
5	3	1	90	230	285	265	265	375	0.8	3.0	3.2	1.63	1.56	1.68	1.59	1.64	1.63	120.5	.															3	3	3	5	5	5	.
5	3	2	170	270	270	250	330	400	1.3	2.5	2.1	1.64	1.66	1.72	1.68	1.35	1.60	.																3	3	3	5	5	5	.
6	1	1	200	260	300	325	375	390	1.9	3.7	3.5	1.36	1.40	1.50	1.49	1.53	1.57	126.5	19	17	2	220	167	135	312	314	360	5955	6771	5706	5.8	5.8	6.8	3	3	3	5	5	5	.
6	1	2	165	205	245	265	310	375	1.3	3.8	3.6	1.40	1.47	1.67	1.59	1.67	1.70	.																3	3	2	6	6	6	2
6	2	1	130	210	250	270	285	330	1.4	2.9	3.1	1.34	1.26	1.47	1.45	1.54	1.59	100.5	.															3	3	3	6	6	6	.
6	2	2	105	195	305	360	365	390	0.9	2.5	3.1	1.42	1.46	1.58	1.59	1.66	1.70	.																3	3	3	6	6	6	.
6	3	1	160	235	250	290	360	400	1.8	3.5	3.2	1.45	1.48	1.46	1.46	1.54	1.55	102.8	.															3	3	3	6	6	5	.
6	3	2	75	145	195	255	255	290	1.2	2.7	3.2	1.53	1.49	1.59	1.54	1.79	1.82	.																2	2	2	1	4	4	.
7	1	1	130	230	290	340	370	395	1.1	3.9	3.8	1.44	1.34	1.51	1.51	1.68	1.63	92.8	47	29	5	271	184	154	314	375	427	4917	5146	6090	4.9	6.0	6.2	3	3	3	6	6	6	.
7	1	2	150	235	280	255	310	330	1.2	3.2	3.0	1.29	1.47	1.56	1.51	1.57	1.68	.																3	3	2	7	6	3	2
7	2	1	150	205	245	285	335	370	1.4	3.4	3.2	1.49	1.42	1.52	1.48	1.67	1.70	93.4	.															3	3	2	7	5	3	.
7	2	2	170	200	260	275	335	385	1.3	2.9	2.4	1.45	1.52	1.56	1.51	1.48	1.52	.																3	4	3	7	8	5	.
7	3	1	95	160	215	280	335	350	1.3	2.9	2.8	1.46	1.43	1.50	1.47	1.59	1.60	94.5	.															4	3	3	7	6	6	.
7	3	2	100	180	245	265	330	380	1.5	2.6	3.0	1.48	1.37	1.48	1.28	1.54	1.42	.																3	4	3	7	8	5	.
8	1	1	170	235	260	320	395	400	2.4	3.2	2.5	1.28	1.30	1.32	1.38	1.33	1.32	128.5	73	27	4	199	171	125	560	600	555	4344	4770	4882	6.6	6.7	7.0	3	4	3	7	8	6	.
8	1	2	180	260	270	305	400	400	2.3	3.1	2.5	1.34	1.34	1.41	1.39	1.35	1.40	.																2	2	2	1	3	4	5
8	2	1	145	200	275	325	390	400	2.2	2.9	2.9	1.35	1.26	1.34	1.33	1.37	1.38	130.0	.															3	2	3	3	1	6	.
8	2	2	160	205	285	325	400	400	2.3	3.2	2.5	1.34	1.22	1.37	1.38	1.34	1.33	.																2	2	2	3	3	4	.
8	3	1	140	210	260	315	400	400	2.2	2.8	2.6	1.26	1.29	1.27	1.30	1.34	1.38	141.0	.															2	2	2	3	3	3	.
8	3	2	165	205	225	310	400	400	2.3	3.2	2.9	1.29	1.32	1.39	1.39	1.32	1.28	.																2	2	2	1	4	4	.
9	1	1	95	210	295	370	400	400	1.1	3.3	2.7	1.36	1.28	1.48	1.42	1.71	1.65	.	39	15	3	242	63	26	159	160	126	5500	5421	3230	7.4	7.4	7.7	2	2	3	3	3	6	.
9	1	2	95	170	250	310	320	325	1.2	2.9	2.9	1.41	1.37	1.58	1.52	1.75	1.65	.																2	2	2	1	3	3	5
9	2	1	20	75	165	260	310	375	0.6	2.9	2.4	1.21	1.22	1.38	1.42	1.64	1.60	.																2	2	2	1	3	3	.
9	2	2	0	70	170	340	400	375	0.8	3.1	2.7	1.32	1.41	1.57	1.59	1.77	1.67	.																2	3	2	1	1	3	.
9	3	1	0	70	180	280	385	320	0.6	2.3	2.0	1.20	1.21	1.36	1.40	1.61	1.48	.																2	3	2	1	6	3	.
9	3	2	50	95	230	340	365	325	0.7	2.7	2.9	1.40	1.45	1.62	1.51	1.76	1.74	.																3	3	3	1	1	5	.
10	1	1	120	155	230	285	350	395	2.2	3.4	2.8	1.36	1.42	1.45	1.50	1.47	1.54	98.0	55	65	8	198	222	103	398	419	382	5530	4355	8199	7.1	7.1	7.6	2	2	3	1	3	5	.
10	1	2	135	210	270	310	375	390	1.8	3.1	3.2	1.42	1.48	1.48	1.49	1.62	1.55	.																3	2	3	1	3	6	4
10	2	1	165	195	260	350	385	390	1.5	2.8	3.3	1.43	1.38	1.41	1.49	1.52	1.55	91.1	.															3	2	2	5	1	3	.
10	2	2	75	140	185	260	340	370	1.4	2.5	3.2	1.45	1.29	1.39	1.44	1.57	1.45	.																3	3	3	1	5	6	.
10	3	1	90	140	185	325	320	253	1.2	2.7	3.1	1.43	1.32	1.48	1.47	1.66	1.57	93.6	.															3	2	2	5	3	3	.
10	3	2	60	120	195	260	320	335	1.4	2.9	2.9	1.35	1.39	1.45	1.50	1.51	1.51	.																3	4	3	1	5	7	.
																																		3	2	3	5	4	6	.

Table A1. Measurements of Soil Parameters and Corn Yields for Each Treatment on Each Farm. (Input data for analysis of variance) (Concluded).

SITE			DICKEY-JOHN						POCKET			BULK DENSITY							FERTILITY												WORMS			PORES			
NO.	TRT	REP	1	2	3	4	5	6	A	AB	B	Ax	Ay	ABx	ABy	Bx	By	YIELD	A	AB	B	A	AB	B	A	AB	B	A	AB	B	A	AB	B	A	AB	B	CR
																			P			K			Mg			Ca			pH							
11	1	1	20	115	210	275	375	400	1.5	2.6	2.5	.	.	1.38	1.48	1.40	1.44	80.9	28	26	2	157	141	127	445	419	487	5360	3152	3689	6.7	6.6	7.0	3	2	2	1	4	3	4
11	1	2	80	195	230	260	315	355	1.9	2.6	2.8	.	.	1.61	1.58	1.72	1.66	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	1	5	5	.
11	1	3	0	140	255	290	295	255	1.0	2.8	2.5	1.54	1.60	1.67	1.71	1.68	1.69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	1	5	5	.
11	1	4	0	95	190	225	260	310	1.0	2.3	2.0	.	.	1.37	1.41	1.48	1.54	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	3	1	4	5	.
11	2	1	180	175	210	265	370	400	1.2	2.6	2.7	.	.	1.51	1.49	1.51	1.55	72.7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	3	3	.
11	2	2	30	145	235	240	295	315	1.4	2.7	2.5	.	.	1.55	1.60	1.58	1.60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	2	1	5	3	.
11	2	3	0	140	205	250	280	315	1.1	2.4	2.9	.	.	1.70	1.67	1.71	1.67	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	2	1	4	3	.
11	2	4	0	80	200	255	250	250	1.2	2.5	2.8	.	.	1.53	1.55	1.54	1.57	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	1	6	6	.
11	3	1	10	95	185	220	295	400	1.3	3.0	2.3	1.36	1.34	1.45	1.45	1.45	1.48	63.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	1	4	4	.
11	3	2	0	115	195	230	320	400	1.2	2.4	2.8	.	.	1.51	1.48	1.50	1.49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	2	1	4	4	.
11	3	3	0	30	145	210	265	305	0.9	2.5	2.6	.	.	1.65	1.68	1.77	1.67	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	1	6	5	.
11	3	4	10	110	190	210	245	245	1.0	2.4	2.9	.	.	1.62	1.57	1.66	1.62	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	3	3	1	5	5	.
12	1	1	70	140	255	310	335	375	0.8	2.3	2.5	1.18	1.11	1.24	1.21	1.58	1.59	169.6	48	48	3	360	265	67	287	311	243	3753	5645	3812	7.0	6.9	7.3	2	2	3	1	1	5	4
12	1	2	80	160	245	295	340	375	0.9	2.5	2.4	1.14	1.15	1.21	1.13	1.64	1.53	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	1	5	.
12	1	3	70	160	205	280	330	385	0.8	2.2	1.7	1.18	1.11	0.99	1.17	1.32	1.24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	4	1	1	7	.
12	1	4	60	140	260	290	355	395	1.0	2.9	3.0	1.27	1.34	1.41	1.38	1.71	1.63	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	3	3	5	.
12	1	5	70	155	240	325	380	395	0.9	2.5	3.3	1.22	1.23	1.30	1.34	1.80	1.64	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	1	5	5	.
12	1	6	40	115	200	240	305	375	0.8	2.5	2.7	1.21	1.17	1.14	1.29	1.36	1.58	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	3	5	6	.
12	2	1	50	140	255	315	375	400	0.7	2.8	2.6	1.40	1.41	1.24	1.19	1.69	1.71	166.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	3	5	.
12	2	2	50	115	215	265	295	350	0.7	1.4	2.3	1.12	1.13	1.20	1.20	1.64	1.47	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	4	5	.
12	2	3	50	145	205	265	290	340	0.7	1.7	.	1.16	1.18	1.19	1.39	1.75	1.58	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	4	1	1	7	.
12	2	4	40	150	240	305	390	400	0.9	1.8	2.4	1.25	1.31	1.39	1.32	1.76	1.42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	1	5	5	.
12	2	5	20	110	210	260	335	355	0.9	1.9	3.4	1.20	1.22	1.31	1.33	1.64	1.56	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	3	5	5	.
12	2	6	60	110	200	270	315	360	1.6	1.8	2.0	1.20	1.19	1.27	1.23	1.46	1.42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	1	5	5	.
12	3	1	40	120	240	295	325	370	0.8	2.3	2.7	1.19	1.20	1.21	1.28	1.57	1.65	166.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	4	5	.
12	3	2	50	110	185	275	345	375	0.9	1.9	2.4	1.11	1.15	1.24	1.21	1.44	1.50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	3	5	.
12	3	3	20	100	170	230	275	320	0.7	1.6	2.1	1.14	1.14	1.29	1.16	1.43	1.59	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	4	1	3	7	.
12	3	4	60	140	265	330	375	400	1.0	2.3	3.0	1.27	1.24	1.36	1.36	1.52	1.60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	3	3	5	5	.
12	3	5	50	110	195	275	330	390	0.9	2.2	2.5	1.14	1.15	1.22	1.27	1.53	1.61	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	3	3	6	.
12	3	6	10	100	185	260	325	375	0.9	1.8	2.6	1.30	1.25	1.23	1.28	1.54	1.60	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	1	3	6	.

Table A2. Soil and Management Data used in Pearson Correlation Analysis.

SITE NO.	REP	DICKEY-JOHN 1	2	3	4	5	6	POCKET A	AB	B	BULK DENSITY Ao	Ay	Alby	Ally	Bt	By	YIELD	WORMS A	AB	B	POREs A	AB	B	CR	Y5 CORN	Y5 SOY	FA CA	T1HP	T2HP	T3HP	T.T. COV. %	TOT. PASS	ORGANIC MATTER A	AB	B	SAND % A	AB	B	SILT % A	AB	B	CLAY % A	AB	B	FERTILIZER RATES N LBS/AC	P LBS/AC	K LBS/AC	FERTILITY A P	A K	A Mg	A Ca	A pH	CUR. WT/PT
1	1	25	90	176	275	370	385	2.0	3.7	3.5	1.35	1.33	1.59	1.50	1.55	1.63	146.4	3	2	3	6	4	6	4	160	57	2	130	95	50	267	10	5.5	5.5	0.9	14	13	12	36	37	41	50	50	47	200	65	30	32	240	397	4852	6.7	5438
1	2	40	140	225	340	370	395	1.7	3.2	3.0	1.26	1.34	1.55	1.50	1.62	1.60	.	3	2	3	8	4	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	3	80	120	180	270	300	315	2.3	3.1	2.8	1.40	1.56	1.59	1.55	1.57	1.59	.	3	2	2	8	4	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	4	95	145	255	293	290	330	1.6	3.1	2.7	1.43	1.43	1.55	1.54	1.63	1.63	.	2	2	2	7	4	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	1	90	180	185	325	380	400	2.5	3.2	2.7	1.46	1.56	1.78	1.71	1.63	1.63	73.8	3	2	3	6	3	5	6	131	51	2	145	60	45	247	9	2.8	2.9	1.0	36	34	20	29	31	36	35	35	44	230	100	55	25	139	350	3771	7.2	5194
3	2	130	190	240	300	320	350	1.5	3.5	3.5	1.43	1.52	1.72	1.72	1.65	1.54	.	2	2	2	1	1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	3	150	230	300	365	385	400	1.6	3.6	3.8	1.51	1.54	1.58	1.53	1.65	1.59	.	3	2	2	1	1	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	4	140	221	280	310	345	380	1.6	3.2	3.5	1.32	1.42	1.49	1.59	1.65	1.64	.	2	2	3	3	3	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	1	90	180	230	320	365	390	1.9	2.6	3.5	1.28	1.27	1.39	1.30	1.55	1.57	141.5	3	3	3	8	6	5	2	136	49	2	175	150	105	270	7	5.5	6.0	2.3	18	18	16	39	38	39	43	43	45	200	80	35	62	233	229	2757	6.1	5383
4	2	140	190	270	305	335	295	1.5	2.6	3.0	1.32	1.21	1.45	1.27	1.50	1.53	.	3	3	3	7	6	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	3	95	195	255	315	365	375	1.5	3.1	3.2	1.46	1.42	1.49	1.46	1.62	1.51	.	4	3	3	7	6	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	4	80	160	235	260	300	355	1.5	2.6	3.0	1.38	1.23	1.47	1.47	1.54	1.57	.	3	4	3	7	8	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
6	1	200	260	300	325	375	390	1.9	3.7	3.5	1.36	1.40	1.50	1.49	1.53	1.57	126.5	3	3	2	6	6	6	2	100	43	2	160	90	66	234	7	4.4	4.0	1.7	23	21	20	42	41	38	35	38	42	170	110	55	19	220	312	5955	5.8	5355
6	2	165	205	245	265	310	375	1.3	3.8	3.6	1.40	1.47	1.67	1.59	1.67	1.70	.	3	3	3	6	6	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7	1	130	230	290	340	370	395	1.1	3.9	3.8	1.44	1.34	1.51	1.51	1.48	1.63	92.8	3	3	2	7	6	3	2	129	47	2	125	125	.	235	7	4.8	4.0	1.6	23	21	19	41	42	40	36	37	40	85	40	60	47	271	314	4917	4.9	4112
7	2	150	235	280	255	310	330	1.2	3.2	3.0	1.29	1.47	1.56	1.51	1.57	1.68	.	3	3	2	7	5	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	1	170	235	260	320	395	400	2.4	3.2	2.5	1.28	1.30	1.32	1.38	1.33	1.32	128.5	2	2	2	1	3	4	5	119	.	3	180	135	70	167	7	7.3	7.5	4.4	4	3	2	41	39	33	55	58	65	180	50	40	73	199	560	4344	6.6	3710
8	2	180	260	270	305	400	400	2.3	3.1	2.5	1.34	1.34	1.41	1.39	1.35	1.40	.	3	2	3	3	1	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10	1	120	155	230	285	350	395	2.2	3.4	2.8	1.36	1.42	1.45	1.50	1.47	1.54	98.0	3	2	3	1	3	6	4	144	.	2	180	96	80	332	8	4.1	4.0	1.5	11	10	14	44	47	46	45	43	40	150	105	100	55	198	398	5530	7.1	9203
10	2	135	210	270	310	375	390	1.8	3.1	3.2	1.42	1.48	1.48	1.49	1.62	1.55	.	3	2	2	5	1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	1	20	115	210	275	375	400	1.5	2.6	2.5	.	.	1.38	1.48	1.40	1.44	80.9	3	2	2	1	4	3	4	92	53	3	150	140	75	192	6	3.2	3.0	1.4	17	14	11	48	48	46	35	38	43	200	45	0	28	157	445	5360	6.7	4508
11	2	80	195	230	260	315	355	1.9	2.6	2.8	.	.	1.61	1.58	1.72	1.66	.	3	3	3	1	5	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	3	0	140	255	290	295	255	1.0	2.8	2.5	1.54	1.60	1.67	1.71	1.68	1.69	.	3	3	3	1	5	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	4	0	95	190	225	260	310	1.0	2.3	2.8	.	.	1.37	1.41	1.48	1.54	.	3	2	3	1	4	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Note: Fields 2, 5, 9, 12, and 13 were omitted from the correlation analysis because of coarse soil textures.

Table A3. Bulk Densities at the 31 cm (Centre Position) Subsoiling Treatments.

Farmer Site no.	Replicate	Horizon	Bulk density (g/cm^3)	X & Y Average bulk density (g/cm^3)
1	1	A	1.40	
1	1	AB	1.46	
1	1	B	1.59	
1	1	Ax	1.40	
1	1	Ay	1.26	1.33
1	1	ABx	1.51	
1	1	ABy	1.30	1.41
1	1	Bx	1.58	
1	1	By	1.62	1.60
2	2	A	1.55	
2	2	AB	1.74	
2	2	B	1.64	
2	2	Ax	1.58	
2	2	Ay	1.61	1.60
2	2	ABx	1.74	
2	2	ABy	1.66	1.70
2	2	Bx	1.64	
2	2	By	1.73	1.69
3	4	A	1.41	
3	4	AB	1.43	
3	4	B	1.54	
3	4	Ax	1.42	
3	4	Ay	1.37	1.40
3	4	ABx	1.49	
3	4	ABy	1.62	1.56
3	4	Bx	1.53	
3	4	By	1.63	1.58
4	4	A	1.44	
4	4	AB	1.40	
4	4	B	1.61	
4	4	Ax	1.33	
4	4	Ay	1.46	1.40
4	4	ABx	1.56	
4	4	ABy	1.48	1.52
4	4	Bx	1.61	
4	4	By	1.58	1.59

Table A3. Bulk Densities at the 31 cm (Centre Position) Subsoiling Treatments (Continued).

Farmer Site no.	Replicate	Horizon	Bulk density (g/cm^3)	X & Y Average bulk density (g/cm^3)
5	2	A	1.59	
5	2	AB	1.67	
5	2	B	1.48	
5	2	Ax	1.64	
5	2	Ay	1.66	1.65
5	2	ABx	1.72	
5	2	ABy	1.68	1.70
5	2	Bx	1.35	
5	2	By	1.60	1.48
6	2	A	1.41	
6	2	AB	1.50	
6	2	B	1.80	
6	2	Ax	1.53	
6	2	Ay	1.49	1.51
6	2	ABx	1.59	
6	2	ABy	1.54	1.57
6	2	Bx	1.79	
6	2	By	1.82	1.81
7	2	A	1.39	
7	2	AB	1.39	
7	2	B	1.57	
7	2	Ax	1.48	
7	2	Ay	1.37	1.42
7	2	ABx	1.48	
7	2	ABy	1.28	1.38
7	2	Bx	1.54	
7	2	By	1.42	1.48
8	2	A	1.31	
8	2	AB	1.30	
8	2	B	1.35	
8	2	Ax	1.29	
8	2	Ay	1.32	1.30
8	2	ABx	1.39	
8	2	ABy	1.39	1.39
8	2	Bx	1.32	
8	2	By	1.28	1.30

Table A3. Bulk Densities at the 31 cm (Centre Position) Subsoiling Treatments (Concluded).

Farmer Site no.	Replicate	Horizon	Bulk density (g/cm^3)	X & Y Average bulk density (g/cm^3)
9	2	A	1.25	
9	2	AB	1.23	
9	2	B	1.68	
9	2	Ax	1.40	
9	2	Ay	1.45	1.42
9	2	ABx	1.62	
9	2	ABy	1.51	1.57
9	2	Bx	1.76	
9	2	By	1.74	1.75
10	1	A	1.41	
10	1	AB	1.49	
10	1	B	1.63	
10	1	Ax	1.43	
10	1	Ay	1.32	1.38
10	1	ABx	1.48	
10	1	ABy	1.47	1.47
10	1	Bx	1.66	
10	1	By	1.57	1.62
11	1	A	1.39	
11	1	AB	1.43	
11	1	B	1.42	
11	1	Ax	1.36	
11	1	Ay	1.34	1.35
11	1	ABx	1.45	
11	1	ABy	1.45	1.45
11	1	Bx	1.45	
11	1	By	1.48	1.47
12	3	A	1.12	
12	3	AB	1.06	
12	3	B	1.38	
12	3	Ax	1.14	
12	3	Ay	1.14	1.14
12	3	ABx	1.29	
12	3	ABy	1.16	1.23
12	3	Bx	1.43	
12	3	By	1.59	1.51

7.3 APPENDIX C

Soil Moisture Conditions:

Soil moisture samples were taken from one to two weeks after the farmers subsoiled with the B.C. sub-mulcher. The rainfall chart for Kent County shows that very little rain fell during this period (June) in between subsoiling and sampling, therefore the moisture data should fairly accurately represent the conditions at the time of the deep tillage.

Table A4. Soil Moisture Content Shortly After Subsoiling.

SITE	SUBSOILED DATE	SAMPLED DATE	% MOISTURE AT 3 DEPTHS (cm) 7.6	17.8	30.5
1	June 4	June 18	19.6	22.8	23.3
2	June 21	June 29	15.0	18.9	21.4
3	June 7	June 20	19.7	21.8	24.4
4	June 14	June 15	21.2	27.3	26.8
5	June 12	June 23	11.0	14.5	16.7
6	June 14	June 23	21.9	25.9	26.6
7	June 16	June 23	19.1	22.9	23.4
8	June 8	June 15	27.9	32.3	34.1
10	June 9	June 15	23.3	27.1	26.5
11	June 17	June 20	18.2	20.4	22.1
12	June 4	June 15	22.3	27.6	28.5

7.4 APPENDIX D

Table A5. Summary of Soil Profile Descriptions.

Site	Soil Layer	Depth (cm)	Texture	Structure* Grade	Size	Kind	Consistence	Rating**
1	A	0-15	C	wk	f	GR	friable	VIIB
	AB	15-34	C	m	m	SAB	firm	VB
	C	34-50	SiC	m	f	SAB	firm	VIB
2	A	0-14	SL		ma		friable	IA
	AB	14-33	SL	ma-wk	c	SAB	firm	IA-VIA
	C	33-50	ScL	wk	m	SAB	friable	IVA-VIA
3	A	0-13	CL	ma-wk	f	SAB	firm	IA-VA
	AB	13-30	CL	m	c	SAB	firm	VB
	C	30-50	C	wk	m	SAB	firm	VB-VIA
4	A	0-10	C	wk	f	GR	friable	VIIA
	AB	10-29	C	m	f	SAB	friable	VIB
	C	29-50	C	m	f	SAB	friable	VIB
5	A	0-11	SL	ma-wk	c	SAB	friable	IA-VIA
	AB	11-30	SL	wk	c	SAB	friable	VIA
	C	30-50	SL	w	m	PL-SAB	friable	VIA
6	A	0- 7	CL	w	f	SAB	friable	VIB
	AB	7-26	CL	m	m	SAB	firm-v firm	VIB
	C	26-50	C	m	f	SAB	firm	VIB
7	A	0- 9	CL	w	f	GR	friable	VIIA
	AB	9-30	CL	m	m	SAB	firm	VIB-VIIB
	C	30-50	C	w	f	SAB	firm	VIA
8	A	0- 6	SiC	w	f	SAB	friable	VA
	AB	6-24	C	w	f	SAB	firm	VA
	C	24-50	HC	m	m	SAB	firm	VB
9	A	0- 9	SL	ma			friable	IA
	AB	9-36	SL	ma-w	vc	SAB	friable	IA-VA
	C	36-50	SL	w	c	SAB	friable	VA
10	A	0-14	SiC	ma-w	m	SAB	friable	IA-VIA
	AB	14-32	SiC	w	f-m	SAB	firm	VA
	C	32-50	SiC	m -	f -	SAB	firm	VIB

Table A5. Summary of Soil Profile Descriptions (Concluded).

Site	Soil Layer	Depth (cm)	Texture	Structure* Grade	Size	Kind	Consistence	Rating**
11	A	0-12	SiCL	ma			friable	IA
	AB	12-31	SiCL	m - f-m		SAB	firm	VB
	C	31-50	SiC	w - f		- SAB	firm	VA-VIA
12	A	0- 9	SL	ma-w-f-SAB			friable	I-VA
	AB	9-30	SL	w-c-SAB-w-f-SAB			friable	VA-VIA
	C	30-50	SL	w - f		- SAB	friable	VIA

* Soil Structure Code:

Grade:	wk	weak
	m	moderate
	ma	massive
	s	strong
Size:	f	fine
	m	medium
	c	coarse
	vc	very coarse
Kind:	GR	granular
	SAB	subangular blocky
	PL	platy

** Ratings as per Table 1.